National Aeronautics and Space Administration

Human Research Program

2008

Cover: Concept artwork of an astronaut on the lunar surface looking toward our fragile and beautiful home.

Message from the Program Manager

2008 was another exceptional year for NASA's Human Research Program (HRP). We made great strides in completing the foundations of our management approach, while delivering several important products needed by NASA's human exploration program.

We delivered several key products described in this report, which supported the preliminary design of the Constellation Program's vehicles, missions, and architectures. In addition, this was the first year we operated with an Integrated Research Plan that clearly identifies the relationship between the tasks we are working and exploration needs. The plan helped us more closely align our work with exploration mission risks and the needs and schedules of the Constellation Program.

We have significantly strengthened the management of health and performance risks to human space explorers by issuing the first edition of the Evidence Book, which provides a comprehensive review of the evidence used to evaluate a risk. The existing evidence or the lack of evidence is key to defining the next steps for research and technology development. A review of the Evidence Book by the Institute of Medicine found it to be an extremely valuable asset to the HRP.

The first independent review of the program management approach, controls, and architecture was held this year. The findings of the Standing Review Board were highly complimentary with only a few issues identified. The board made particular note of the outstanding personnel and use of the innovative human risk-based management architecture.

We continued to engage the U.S. research community through 4 research solicitations and a variety of workshops and working groups. The largest annual solicitation for multidiscipline biomedical research was again issued jointly between NASA and the National Space Biomedical Research Institute.

This year we continued to strengthen our partnerships with domestic agencies and the international space life sciences community. Most notably, we made strides with the European Space Agency on International Space Station experiments and capabilities and with Russia on the upcoming 105-day isolation and confinement study.

We expanded our education and outreach activities, creating several new and exciting video and graphics products as well as podcasts and exhibits, such as the Smithsonian Folklife Festival in Washington, DC.

We will continue to become better organized, more productive and focused on the right things to ensure a highly successful human space exploration program.

Dennis J. Grounds
Program Manager

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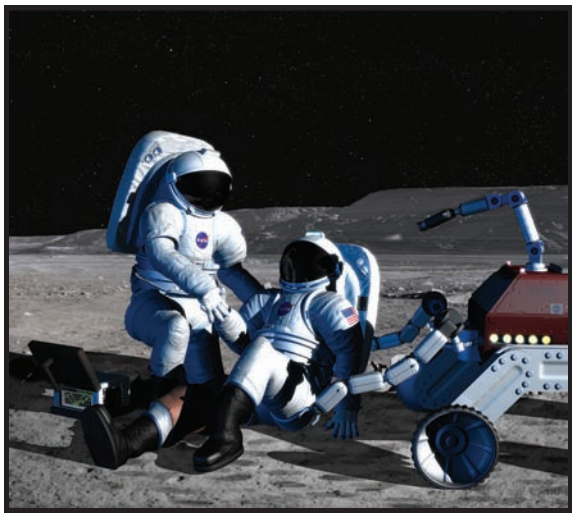
Background

Crew health and performance is critical to successful human exploration beyond low Earth orbit. Risks include physiological effects from radiation, hypogravity, and planetary environments, as well as unique challenges in medical treatment, human factors, and behavioral health support. The HRP investigates and mitigates the highest risks to human health and performance, providing essential countermeasures and technologies for human space exploration.

In its third year of operation, HRP continued implementation of the evidence-risks-gaps-tasks-deliverables management architecture. Products were delivered to support preliminary design of the Constellation vehicles. Experiment operations continued in ground analogs and on ISS, providing data to further understand the impact of the space environment on the human system. The research results contributed to the scientific knowledge and technology developments to address the human health and performance risks.



The HRP also completed 2 significant external reviews. The Institute of Medicine reviewed the Evidence Book, a comprehensive assessment of the evidence used to evaluate a risk. An external Standing Review Board evaluated the program management structure and processes. Inputs from both reviews were used to benefit program implementation and further align tasks with the most important gaps in knowledge.

As indicated in this report, we made significant programmatic and scientific progress towards reducing crew health and performance risks and advancing medical care and countermeasure systems for missions to the Moon and beyond.

Goals 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. The HRP's objectives are to:

1. Develop capabilities, necessary countermeasures, and technologies in support of human space exploration, focusing on mitigating the highest risks to crew health and performance.
2. Sponsor research and technology development that enables the definition and improvement of human spaceflight medical, environmental, and human factors standards
3. Develop technologies that serve to reduce medical and environmental risks, to reduce human-systems resource requirements (e.g., mass, volume, power, data), and to ensure effective human-system integration across exploration systems.

4. 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

Strategically, the HRP conducts research and technology development that: 1) enable the development or modification of Agency-level human health and performance standards by the Office of the Chief Health and Medical Officer and 2) provide the Exploration Systems Mission Directorate with methods of meeting those standards in the design, development, and operation of mission systems. The HRP resides within the Exploration Systems Mission Directorate. Figure 1 shows the organizational structure of the directorate, including the HRP.

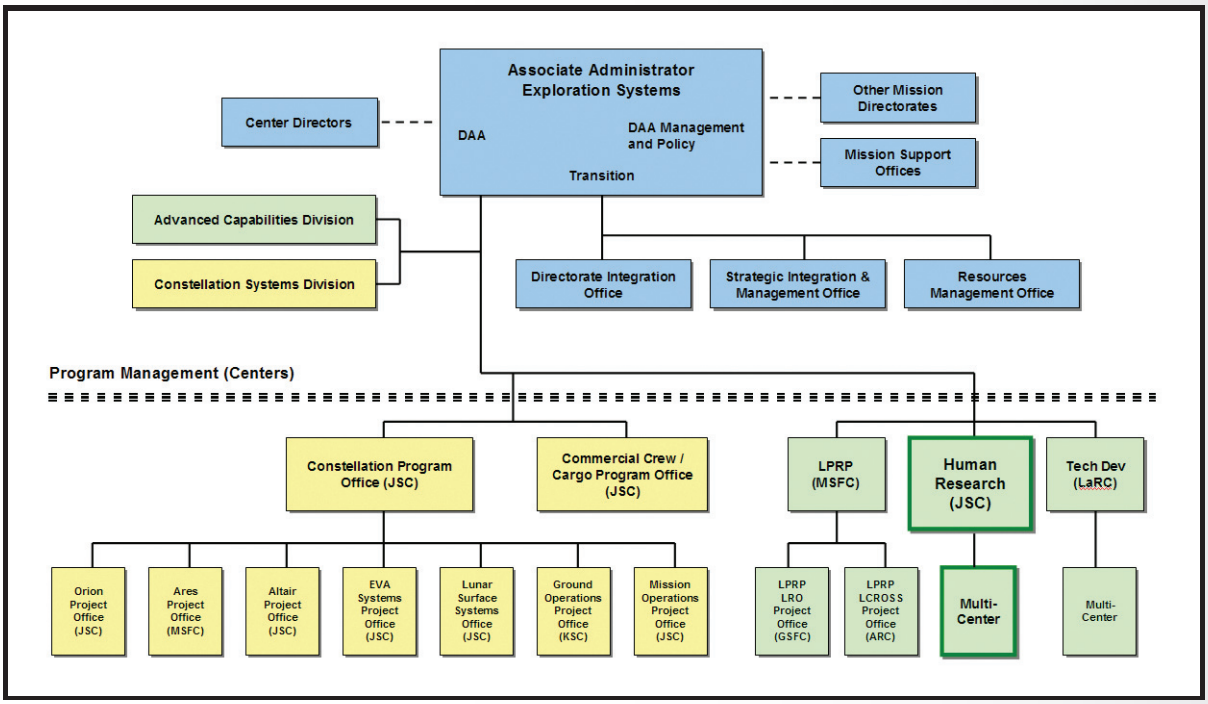


Figure 1. Organizational structure of the Exploration Systems Mission Directorate including the HRP.

The HRP organization is designed to support and accomplish the goals of the Exploration Systems Mission Directorate and Office of the Chief Health and Medical Officer, as indicated in Figure 2. The Program Manager and deputy lead all aspects of the program. The Program Scientist and deputy lead the science management and coordination. Two offices support program and science management and provide integration across the elements. Six elements comprise the HRP and are focused to accomplish specific goals for investigating and mitigating the highest risks to astronaut health and performance.

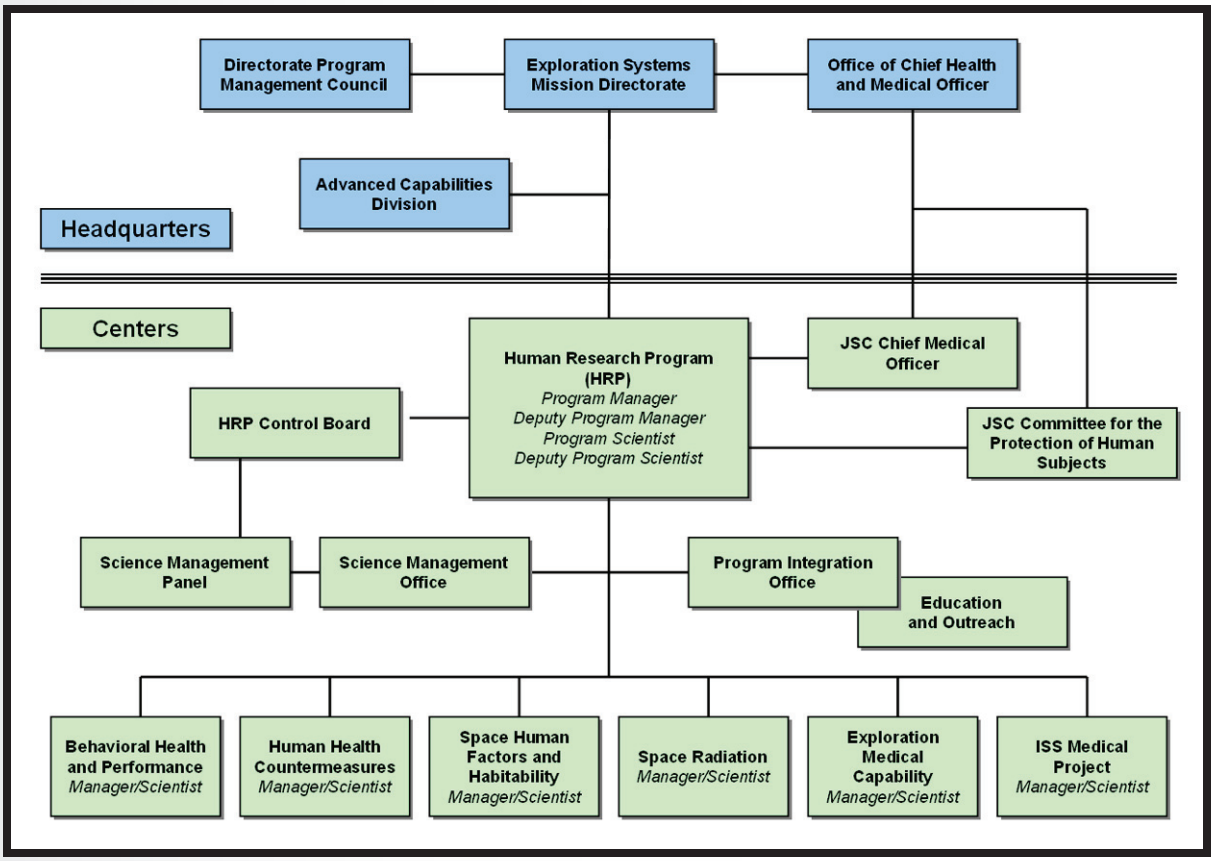


Figure 2. Organizational structure of the HRP.

The Science Management Office and Program Integration Office provide key integration of activities across the program in support of the Program Manager, Program Scientist, and elements. The Science Management Office maintains scientific integrity of the research, reviews and integrates science tasks across the elements, reviews the prioritization and implementation of flight and ground analog tasks, communicates research needs to other programs within NASA (e.g., Constellation), and cultivates strategic research partnerships with other domestic and international agencies. The Program Integration Office provides program planning, integration, and coordination across the program. This office ensures close coordination of exploration customer needs and HRP deliverables to meet those needs.

The program is divided into 6 major elements: ISS Medical Project, Space Radiation, Human Health Countermeasures, Exploration Medical Capability, Space Human Factors & Habitability and Behavioral Health & Performance. These elements provide the program knowledge and capabilities to conduct research to address the human health and performance risks as well as advance the readiness levels of technology and countermeasures to the point of transfer to the customer programs and organizations. An element consists of the aggregation of related projects and research tasks focused toward developing products that reduce risks to the crew.

Management of the program and elements is at the Johnson Space Center. Research and technology development expertise is provided by the Johnson Space Center as well as other NASA centers, specifically the Ames Research Center, Glenn Research Center, Kennedy Space Center, and Langley Research Center. With a OneNASA approach, the numerous NASA centers provide core competencies and additional research capabilities to meet HRP goals. For example, the Space Radiation effort includes work performed at the Johnson Space Center and the Langley and Ames Research Centers. The Behavioral Health and Performance and Space Human Factors and Habitability teams are from the Johnson Space Center and Ames Research Center. The Exploration Medical Capability effort and the Human Health Countermeasures work are performed at the Johnson Space Center and the Glenn and Ames Research Centers. The Kennedy Space Center and the Ames Research Center support the International Space Station Medical Project with baseline data collection, launch and landing support, and international experiment coordination.

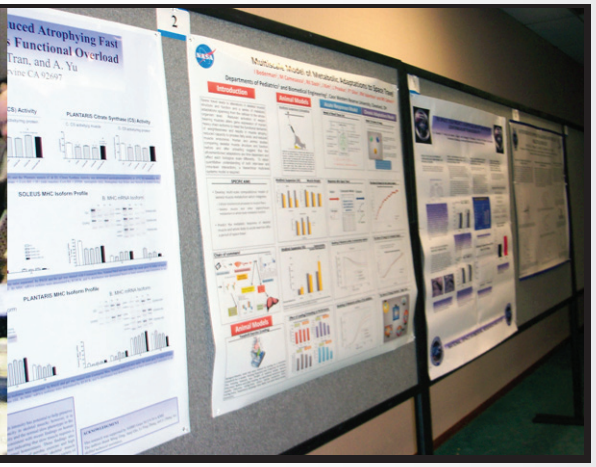
Additional information about the program can be found at: **http://humanresearch.jsc.nasa.gov**.

Partnerships and Collaborations

In partnership with the HRP, the National Space Biomedical Research Institute (NSBRI) investigates the physical and psychological challenges of long-duration human spaceflight. Founded in 1997 through a NASA competition, the NSBRI is a non-profit research consortium that bridges the research, technical, and clinical expertise of the biomedical community with the scientific, engineering, and operational expertise of NASA. The NSBRI is dedicated to advancing biomedical research to ensure a safe and productive long-term human presence in space.

The scientific research community is critical for the success of the HRP and human space exploration. The HRP sponsored the 2008 Investigator's Workshop at South Shore Harbor in League City, Texas, with more than 350 attendees including NASA, NSBRI, and extramural investigators holding grants from the program. Participants shared information regarding the current status and significant results of research and technology developments for the HRP human health and performance risks. This annual workshop was a beneficial forum for disseminating knowledge and fostering collaboration within the research community.

Workshop participants listen to one of the many presentation topics.



Example of research posters used for discussion during risk sessions

The HRP works with universities, hospitals, and federal and international agencies for the purpose of sharing research facilities, multi-user hardware, and collaboration on research tasks of mutual interest. The HRP uses bed rest facilities at the University of Texas Medical Branch in Galveston, Texas, as a spaceflight analog to study changes in physiological function associated with spaceflight. The NASA Space Radiation Laboratory at the DoE's Brookhaven National Laboratory is used to conduct research using accelerator-based simulation of space radiation. The HRP also uses radiation research facilities at the Loma Linda University Medical Center. The General Clinical Research Center and the Lerner Research Institute at the Cleveland Clinic provide facilities supporting the HRP. These facilities provide bed rest and 6-degree head-down tilt simulation along with a Zero-gravity Locomotion Simulator, a horizontal treadmill providing footfall forces and conditioning similar to that of the treadmill used on ISS. The HRP also maintains collaborative relationships with the International Partners through various working groups. These relationships enhance the research capabilities and provide synergism between the research efforts among countries.

HRP partnerships and collaborations (examples)	Benefits to Exploration
National Space Biomedical Research Institute	Alignment of research and technology development
Universities Space Research Association	Capabilities of the university community and other sources of knowledge transfer
International Space Life Sciences Working Group with members from Canada, Japan, Germany, Ukraine, France, and the European Space Agency	Optimized collaborative research with ground analogs
Joint Working Group with Russia	Synergy in research and operations, optimal use of the ISS
National Institutes of Health (NIH), the Department of Energy, the Centers for Disease Control and Prevention, the Department of Agriculture, and the Department of Defense	State-of-the-art research facilities and research activities and technology development of mutual interest
Cleveland Clinic	Human Health Countermeasures Element
Aquarius Habitat (NASA Extreme Environment Mission Operations [NEEMO] operated by the University of North Carolina) and other analog environments such as Antarctica and Devon Island	Human Health Countermeasures, Exploration Medical Capability, and Behavioral Health and Performance elements benefit from the analog environment
University of Texas Medical Branch in Galveston	Bed rest facilities
Brookhaven National Laboratory	State-of-the-art facility to perform radiobiology and physics experiments
Loma Linda University	Space radiation research and facilities

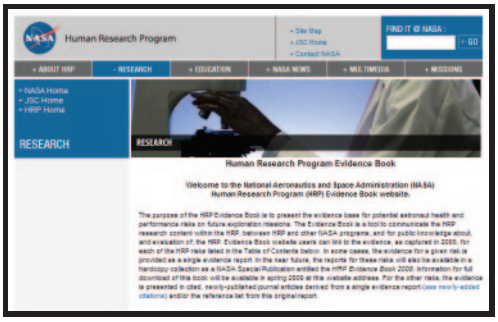
Examples of partnerships and collaborative relationships with universities, industries, and government agencies.

Major Programmatic Accomplishments

Evidence Book

The HRP's Evidence Book is a collection of evidence-based risk reports for each risk contained within the HRP's requirements document. Thus, the book provides the current record of the state of knowledge from ground and space research and operations for each of the defined human health and performance risks for future NASA exploration missions. The evidence reports provide a brief review article containing the evidence related to a specified risk, written at a level appropriate for the scientifically-educated, non-specialist reader.

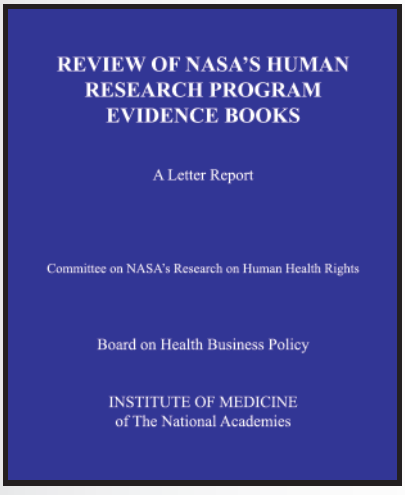
The 2008 Evidence Book is a collection of evidence-based risk reports created from the information presented verbally and discussed within the Programmatic Review in 2006. These reports were co-authored by members of the Discipline Integrated Product Teams that contain representatives from the HRP's research, NSBRI, and medical operations communities.



Home website page for the HRP Evidence Book.

Individual revised risk evidence reports and cited journal articles were placed on the externally available website (**http://humanresearch.jsc.nasa.gov/elements/smo/hrp_evidence_book.asp**) in a format that allows a user to link to the evidence available for each risk. Future generations of the HRP's Evidence Book are expected to be maintained in an electronic and rapidly updatable text format that promotes comment to the current evidence content and identification of previously unexplored data or interpretations.

Institute of Medicine Review of Relevant Exploration Risks



The Institute of Medicine's "A Letter Report".

The February 2008 versions of the Evidence-Based Risk Reports were reviewed by members of a committee on NASA's Research on Human Health Risks, established by the Institute of Medicine. The resulting thorough Review of *NASA's Human Research Program Evidence Books: A Letter Report (2008)* provided outstanding guidance for both the revision of the current risk reports and for the development of future versions. This review also offered excellent suggestions to improve public access to the information in these reports.

Program Implementation Review

In 2008, the HRP completed its first independent, external review of the program organization and management processes. The purpose of the Program Implementation Review was to ensure program scope and content are aligned with the Agency vision and goals, program implementation follows the Program Plan, and performance, cost, and schedule commitments are being met. The review orientation was held in May with HRP personnel presenting program, element, and project content to the Standing Review Board in July.

The final briefing and report from the board was completed in early September. The board was highly complimentary of the HRP leadership and program personnel, evidence-risks-gaps-tasks-deliverables management architecture, customer focus, and processes implemented. Identified issues include criticality of the HRP within NASA, availability of ISS resources, and data accessibility. The Standing Review Board recommendations and responding HRP action plans were presented in November to the Exploration Systems Mission Directorate Program Management Council and then the Agency Program Management Council. Both councils approved continuation of the HRP with the program recommended changes, which the HRP is currently implementing.

Human System Risk Board

Human system risks encompass environmental exposures, crew performance issues, biomedical stressors/susceptibilities, the ability to provide medical care, and any other challenges that affect the human as a system. The Chief Health and Medical Officer is the NASA Health and Medical Technical Authority (HMTA) and appoints a Chief Medical Officer designee at each center. The Johnson Space Center officer established the Human System Risk Board to ensure a consistent, integrated process was established and maintained for managing human system risks.

In 2008, the Human System Risk Board presided over two risks within the HRP portfolio. Results were presented from the Renal Stone Risk during Spaceflight: Assessment and Countermeasure Validation, a study completed under the HRP's Non-Exercise Physiological Countermeasures Project. In addition to hydration and dietary recommendations, potassium citrate was recommended as an operational countermeasure to renal stone formation based on results of the inflight study. The board concurred with this recommendation and to transition potassium citrate to medical practice. The Human System Risk Board also received a presentation regarding a new risk, Risk of Adverse Health Effects due to Alterations in Host-Microorganism Interactions. This new risk was the result of the Institute of Medicine review of the Evidence Report for the Risk of Crew-Adverse Health Event due to Altered Immune Response, recommending that NASA "Develop evidence books on additional risks, including alterations in microbe and host interactions…". The Human System Risk Board agreed to assign this risk to the HRP with initial work to determine if recent evidence from spaceflight experiments has clinical implications and, if so, what research is necessary to provide an adequate knowledge base to assess the risk and develop necessary countermeasures to mitigate.

Solicitations

NASA, in partnership with the NSBRI, released a research announcement entitled, “Research and Technology Development to Support Crew Health and Performance in Space Exploration Missions” in August 2007. Proposals were solicited by the HRP in the areas of bone, cardiovascular, muscle, nutrition, and lunar analog bed rest investigations. NSBRI topic areas included bone loss, cardiovascular alterations, human performance factors, sleep and chronobiology, muscle alterations and atrophy, neurobehavioral and psychosocial factors, nutrition, physical fitness and rehabilitation, sensorimotor adaptation, and smart medical systems and technology development. The review process consisted of a relevancy review of proposal synopsis (step 1) and a scientific merit and program alignment review (step 2); 196 proposals were submitted in response to the solicitation and 132 were invited to submit a full proposal for step 2 evaluation. In April 2008, NASA and NSBRI announced the 33 successful proposals that were funded to address astronaut health and performance on future space exploration missions.

Several solicitations were conducted in 2008 for space radiation research. The Ground-Based Studies in Space Radiation NASA research announcement was released in January 2008. Proposals were solicited in the area of space radiation biology using beams of high energy heavy ions simulating space radiation at the NASA Space Radiation Laboratory at the Brookhaven National Laboratory. Nine awards were announced in September 2008. The 2008 NASA Specialized Centers of Research’s research announcement for cancer and central nervous system research was released in September 2008. This solicitation seeks research that will provide the basis for improved estimation and uncertainty reduction for solid cancer, leukemia, and central nervous system risks from space radiation. Awards will be announced in April 2009. In February 2008, the NSBRI solicited proposals for a Center of Acute Radiation Research addressing acute radiation effects associated to solar particle events using beams of protons and high-energy heavy ions delivered at the NASA Space Radiation Laboratory and at Loma Linda University Medical Center Proton Treatment Center. The winner of the 5-year award was announced in October 2008.

In August 2008, NASA and NSBRI released a research announcement entitled “Research and Technology Development to Support Crew Health and Performance in Space Exploration Missions”. NASA solicited proposals in the areas of behavioral health and performance, muscle, sensorimotor, and space human factors and habitability. The NSBRI solicited proposals in the areas of bone loss, cardiovascular alterations, human factors and performance, muscle alterations and atrophy, neurobehavioral and psychosocial factors, sensorimotor adaptation, and smart medical systems and technology. Awards will be announced in April 2009.

Small Business Innovation Research (SBIR) announcement.

We continued participation in the Small Business Innovation Research (SBIR) program in 2008. Our SBIR topic areas were exploration crew health capabilities, exploration medical capability, behavioral health and performance, space human factors and food systems, space radiation, and inflight biological sample preservation and analysis. NASA announced 8 HRP SBIR 2007 Phase 2 awards in October 2008 and 18 HRP SBIR 2008 Phase 1 awards in November 2008.

Specific technologies of interest selected for the HRP 2008 topics included: a crew exercise system, oxygen concentrators, blood analysis systems, behavioral health and fatigue assessment tools, human factors reporting tools, food preservation barriers, a small personal dosimeter, neutron spectrometer, an active charged particle spectrometer, a chromatin painting technology, and small flow cytometry and cell counting systems. The Elements within the HRP use the SBIR program to complement their research, benefiting both NASA and industry.

Major Technical Accomplishments

Renal Stone (Human Health Countermeasures Element, Non-Exercise Physiological Countermeasures Project)

Highlights for 2008 include the recommendation of potassium citrate as a countermeasure for renal stone formation and the transition from the flight investigation to medical practice. The renal stone countermeasure presentation was given at the Human Systems Risk Board in November 2008. Based on the presentation, the Johnson Space Center's Chief Medical Officer requested that this countermeasure begin the transition to medical practice process. This review process is designed to assess the effectiveness and operational readiness of medical research. The first step in this process was to bring the results to the Space Medicine Configuration Control Board for review and recommendation. The results of the investigation were presented to the Medical Operations Panel and the Space Medicine Configuration Control Board (December 2008) where the endorsement and recommendation to proceed with operational implementation through Space Medicine was received. The team will continue in 2009 with transitioning to medical practice by sending a memo to the Johnson Space Center's Chief Medical Officer who will convene a panel of external experts for concurrence and then to the Office of the Chief Health Medical Officer at NASA Headquarters for final approval.

Example of a renal stone.

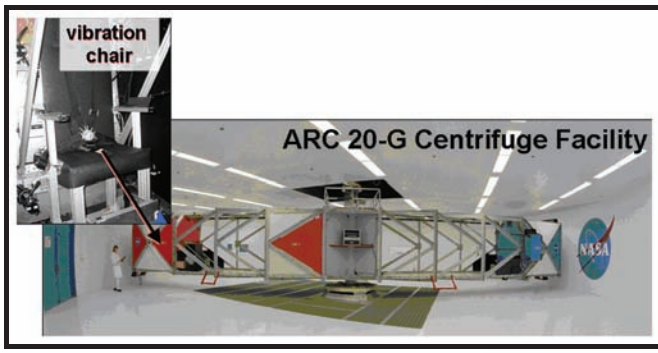
Human Performance Under Combined Vibration and Acceleration (Space Human Factors & Habitability Element, Space Human Factors Engineering Project)

The Constellation Program is developing multiple vehicles for future space exploration, such as the Ares-I rocket for lift capability and the Orion vehicle for crew transportation. Because of thrust oscillation in the first stage of the new Ares-I rocket, the next-generation Orion vehicle, may produce crew vibration significantly greater than was experienced during the Mercury, Gemini, and Apollo launches. Moreover, the Orion display and control interfaces are significantly more advanced from those historic space programs when human vibration tolerance was last addressed by NASA. To assess visual performance for modern display technologies under the combined 12-Hz whole-body vibration and elevated 3.8-gravity loading expected during Ares-I launch, several studies were completed in 2008 using a vibration chair installed on the NASA Ames Research Center's 20-G centrifuge.

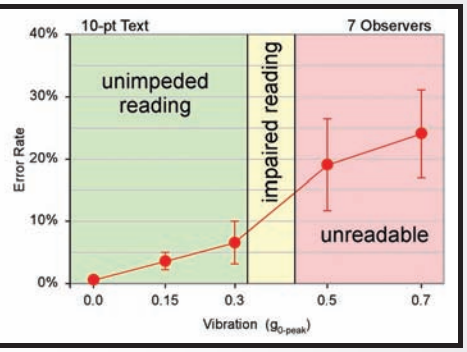
General population and Astronaut Office studies with Orion-inspired numerical computer display formats demonstrated significant losses in readability, as measured objectively in terms of response time and error rates, at vibration levels of 0.5 gravity and 0.7 gravity (0-peak), but not at 0.3 gravity for 10-pt text size. For 14-pt text, decrements were significant at 0.7 gravity (0-peak), but not 0.5 gravity.

In a separate study of display usability, Astronaut Office participants' subjective self-assessments indicated that visual scanning was compromised at vibration levels consistent with those that caused objective losses in readability. Comparisons showed that increasing from the 1-G Earth's gravity to the 3.8-gravity centrifuge acceleration diminished visual tolerance to vibration. Additionally, the graphical display formats were generally observed to be less susceptible than text to vibration disturbances, especially when at 3.8-gravity on the centrifuge.

All study results were provided to the Constellation Program to evaluate current vehicle designs against the crewmember's ability to read under combined G-loading and vibration conditions anticipated during Orion launch.



Vibration chair on Ames Research Center's 20-G centrifuge



Astronaut Office participants' objective reading performance (error rate) superimposed on subjective assessment of display readability (green-yellow-red background) for 10-point numeric text

Constellation Architecture Support (Space Radiation Element)

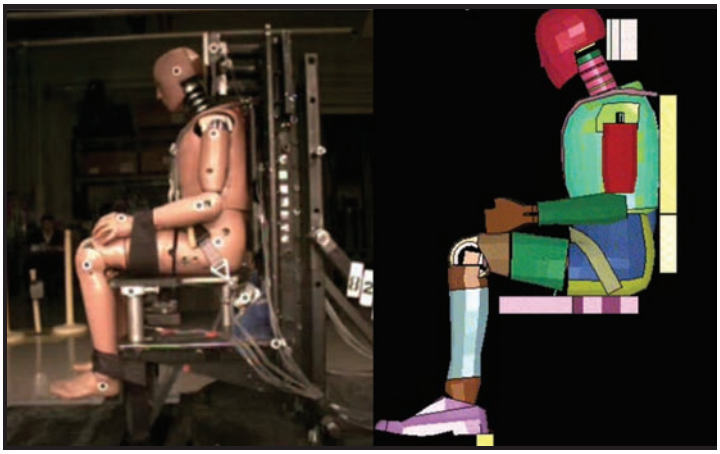
The Space Radiation Element directly supported Constellation vehicle assessments and architecture studies throughout 2008 to ensure crew radiation exposure risks are minimized during both lunar sortie and lunar outpost missions. Radiation shielding assessments for the Altair Lunar Lander and candidate pressurized Lunar Electric Rovers were performed to support the design of solar storm shelters to prevent the risk of acute radiation syndromes and to reduce the risk of radiation carcinogenesis. Risk assessments were performed for the Constellation Architecture teams to evaluate the effects of crew selection and projected time in solar cycle to accomplish missions of 180 days while maintaining crew radiation exposure below acceptable limits. The Space Radiation Element used the newly developed probabilistic risk assessment tool and the OLTARIS design tool website for the analyses as well as the evaluation of flexible shielding technologies being developed by the Exploration Technology Development Program. The Space Radiation Element's 2008 upgrades to the OLTARIS radiation analysis and design tool website (OLTARIS.larc.nasa.gov) incorporate the latest nuclear physics improvements to high charge and energy transport including more accurate light ion propagation and neutron transport methodologies as well as lunar surface design capabilities.

Occupant Protection (Human Health Countermeasures Element, EVA Physiology, Systems & Performance Project)

The EVA Physiology, Systems & Performance Project team is working with Constellation's Orion

Landing Steering Committee to develop, verify, validate, and accredit biodynamics models using a variety of crash and injury databases that include NASCAR, Indy Car, and military aircraft. These biodynamics models will be used by Constellation to evaluate a variety of vehicle, seat, and restraint designs in the context of multiple nominal and off-nominal landing scenarios. These models are being used in conjunction with Acceptable Injury Risk definitions to provide improved occupant protection requirements to the Constellation's Human Systems Integration Requirements document.

Race car and military aircraft occupant protection experience suggests that significant benefits can be gained from improved seat and restraint systems. Existing NASA occupant protection requirements may not adequately account for seat-restraint systems and their associated injury responses to a range of landing loads. The EVA Physiology, Systems & Performance Project team has coordinated a panel of subject matter experts from automotive, racing, and military occupant protection backgrounds to assist in refining the Constellation's Human Systems Integration Requirements and improve protection for the crew. This multidisciplinary team conducted a thorough review of existing literature and standards for biodynamic responses associated with injury and provided updated-biodynamic-response injury-threshold recommendations to Constellation and inputs to the Constellation's Human Systems Integration Requirements document.



Biodynamic models of seat/restraint systems are validated with sled test results.

The team includes biodynamic modeling experts who are developing numerical models of NASCAR seats and restraint systems. Preliminary validation of the models was performed in 2008 using a series of sled tests conducted at Wright Patterson Air Force Base. The results of the sled tests were correlated with the models by directly comparing the physical automated test dummy responses to the predicted model responses. Currently, these models are being used to re-create computer simulations of actual NASCAR crashes. Injury responses predicted by the model will be correlated with the known injuries sustained by the driver. This effort will allow the team to define the probability of injury based on each biodynamic response. These biodynamic response predictors will then be used to evaluate Orion landing risk.

To put Orion landing risk in perspective, the team compiled information from other military and civilian vehicle operations based on overall risk of injury, probability of an off-nominal event, and the risk of injury in an off-nominal event. Subsequently, an Operationally Relevant Injury Scale is being defined to allow classification of potential injuries and their impacts to crew performance and egress. The information compiled through these efforts will help to define what level of risk is acceptable for occupant protection within the Constellation Program, taking into account key mission drivers such as crew health, safety, and operational performance.

Stability of Pharmacotherapeutic and Nutritional Compounds (Stability) (Human Health Countermeasures Element, Non-Exercise Physiological Countermeasures Project)

Four identical sample kits containing pharmaceuticals, food, dosimeter, and a temperature sensor were delivered to ISS and stored for various time durations prior to return to Earth for analysis of degradation.

A study was conducted on the stability and shelf-life of pharmaceutical and nutritional compounds to assess the effects of space radiation and long-term storage on ISS on complex organic molecules, such as vitamins and amino acids in space food items and medicines commonly found in the space medical kit. Results will help researchers develop more stable and efficacious pharmaceutical and nutritional countermeasures suitable for future long-duration missions to the Moon and Mars. Analysis of certain medications returned from the Shuttle and ISS in an earlier study indicated that some of the pharmaceuticals flown on the Shuttle and ISS degraded in space. This may compromise treatment efficacy and health of crews on future exploration missions. This study will identify those pharmaceuticals and nutrients that degrade in space and assess the magnitude and time course of degradation. This information can be used in mathematical models to predict the shelf life of products for long-duration exploration missions and guide future efforts to develop alternative formulations, packaging, and shielding materials for medicines and foods. Four kits were launched to ISS on STS-121 in July 2006 while 4 identical kits were kept in a controlled ground environment simulating ISS temperature and humidity. The first kit was returned on STS-121, the second kit returned on STS-117 in June 2007, and the third kit returned on STS-122 in February 2008. The final kit was returned on STS-126 in November 2008 after 29 months in a microgravity environment and samples are currently being studied by the Nutritional Biochemistry and Pharmacotherapeutics laboratories to evaluate any changes in nutrient content of food and pharmaceutical quality during long-duration spaceflight. This study is essential to determine the safety of foods and drugs on orbit for extended periods of time, especially as we anticipate exploration class missions.

Actiwatch (Behavioral Health & Performance Element)

Astronaut Sunita Williams wearing the Actiwatch.

Data collected from spaceflight consistently indicates that sleep loss occurs to varying degrees for some individuals during spaceflight missions. Extensive ground-based scientific studies, including controlled laboratory research as well as data gathered from other industries, demonstrate that a lack of sleep often results in performance errors and impacts long-term health.

The Sleep-Wake Actigraphy and Light Exposure study serves as the largest assessment of sleep ever conducted during spaceflight. During this investigation, crew members on both Shuttle and ISS missions wear an Actiwatch-L, a small activity and light recording device, throughout their mission. The sleep-wake activity and light exposure data gathered will characterize sleep in space for both short and

long-duration missions. Additional information collected during this investigation addresses gaps related to adaptation to the spaceflight environment, and countermeasure development.

The high number of astronauts participating in this study as well as the positive comments from NASA flight surgeons emphasizes the usefulness of this technology. The feedback from the operational community has led us to begin transitioning the Actiwatch protocol to medical practices. In fact, real-time data shared during several of the ISS missions with the researcher, flight surgeon, and the astronaut has led to changes in shift schedules that protect sleep and wake hours.

Significant Facility Hardware and Inflight Accomplishments (International Space Station Medical Project)

The Human Research Facility (HRF) racks 1 and 2 were disconnected and moved in October 2008 from the U.S. Laboratory module to their new permanent locations in the European Columbus module, which became part of the ISS assembly in February 2008. Subsequent check outs of each rack were successful and experiment operations were resumed without interruption in the Columbus module. Movement of these racks allowed for co-location of European Space Agency-provided and NASA-provided research hardware for human life sciences investigations.

HRF Rack 1 contains the ISS ultrasound instrument for imaging studies and the Space Linear Acceleration Mass Measurement Device for monitoring body weights.

HRF Rack 2 contains the refrigerated centrifuge for processing biological samples, a personal workstation for collecting data, and the pulmonary function system for supporting research on the ISS.

Gagarin Cosmonaut Training Center Facility Upgrade (International Space Station Medical Project)

The Yu. A. Gagarin State Scientific Research-and-Testing Cosmonaut Training Center located in Star City, Russia, was constructed in 1960 and is the location for astronaut and cosmonaut training and cosmonaut rehabilitation after spaceflights. At this site, scientists and medical doctors perform experimental and medical tests on ISS crewmembers launching and landing in Russia, and biological samples are analyzed for postflight health assessments and research. In 2008, under a collaborative agreement, the facilities used by the NASA medical and human life sciences personnel was

significantly remodeled and refurbished. New ceilings, floors, cabinets, sinks, and laboratory refrigerators were installed to facilitate clinical testing and research. The improvements to this facility have enhanced the capabilities including upgraded lighting and electrical power, increasing the safety of personnel and crewmembers, and providing for the opportunities for increased human testing. With these enhancements, we will be able to accommodate newer and larger hardware setups for future HRP science experiments, as well as medical testing and cooperative International Partner scientific investigations.

Gagarin Cosmonaut Training Center (Star City, Russia) is the site of ISS crewmember training and pre- and postflight medical and research testing.

Research Elements Overview

The HRP uses the 6 elements to mitigate human health and performance risks and to establish the evidence base on which human spaceflight health standards are based. These standards include fitness for duty standards that define the physiological and behavioral parameters necessary to maintain performance; the permissible exposure limits during spaceflight conditions; and levels of care standards that define the medical capabilities needed to respond to a medical contingency. The descriptions and detailed accomplishments for each element are discussed in the following sections.

The elements include:
- International Space Station Medical Project
- Space Radiation
- Human Health Countermeasures
- Exploration Medical Capability
- Space Human Factors & Habitability
- Behavioral Health & Performance

International Space Station Medical Project (ISSMP)

The International Space Station Medical Project (ISSMP) was created to focus use of ISS on the research necessary to close current knowledge gaps to help NASA reduce the risks to the human system during exploration missions. The ISSMP provides the bridge between flight research and medical operations by planning, integrating, and implementing human research requiring access to ISS, Shuttle, Soyuz, Progress, or other spaceflight vehicles. This support spans preflight and postflight ground activities and inflight science operations, and also includes access to on orbit assets including sustaining engineering of the Human Research Facility. During 2008, the ISSMP coordinated and optimized the research supporting 4 Shuttle missions (STS-122, 123, 124, 126) and 3 ISS missions (Increments 16–18). Among these, 4 investigations completed inflight operations and 7 studies continued inflight operations. Also in 2008, 8 investigations were selected for flight and 4 investigations initiated development of flight procedures and flight hardware. The following table provides a list of all ISSMP flight experiments, their required subject number, and status to date.

Current International Space Station Medical Project Flight Investigations

Investigator Title	Ops Title	Subjects		Status (as of December, 2008)
		Required	Completed	
Stability of Pharmacotherapeutic and Nutritional Compounds	Stability	4 kits	4 kits	Flight activities completed, final kit returned, sample and data analysis in progress
Periodic Fitness Exam Oxygen Uptake Measurements	PFE-OUM	7	7	All crewmembers completed, final postflight baseline data collection completed in January, 2009, data analysis in progress
Bioavailability and Performance Effects of Promethazine During Spaceflight	PMZ	24	6	9 PMZ and 5 control subjects were obtained prior to ending data collection on STS-122.
Nutritional Status Assessment	Nutrition	24	6	Crewmembers participating during Increment 18, Flight samples returned from Increment 16-17 and analysis in progress
Cardiovascular and Cerebrovascular Control on Return from ISS	CCISS	6	2	Crewmembers participating during Increment 18, planned completion of study expected after Increment 20/21
Sleep-Wake Actigraphy and Light Exposure During Spaceflight	Sleep	All Shuttle 20 ISS	48 Shuttle 7 ISS	Study has successfully recruited ISS crewmembers for Increments 18-21

Current International Space Station Medical Project Flight Investigations

Investigator Title	Ops Title	Subjects		Status (as of December, 2008)
		Required	Completed	
Validation of On-Orbit Methodology for the Assessment of Cardiac Function and Changes in the Circulating Volume Using "Braslet-M" Occlusion Cuffs	Braslet	10 scans	5 scans	Investigation currently in progress during Increment 18
Validation of Procedures for Monitoring Crewmember Immune Function	Integrated Immune	17 Shuttle 17 ISS	9 Shuttle 4 ISS	Study has successfully recruited ISS crewmembers for Increments 18-21, Shuttle phase of study expected to be completed in 2009
Space Flight-Induced Reactivation of Latent Epstein-Barr Virus	Epstein Barr	41 Shuttle 17 ISS	36 Shuttle 16 ISS	Investigation is scheduled to fly its final subjects on Shuttle in early 2009. Long-duration subjects awaiting final postflight data collection.
Behavioral Issues Associated With Long-Duration Space Missions: Review and Analysis of Astronaut Journals	Journals	10	10	An additional crewmember is participating during Increment 18 representing the final crewmember for this investigation
Bisphosphonates as a Countermeasure to Space Flight Induced Bone Loss Preflight Zoledronate Infusion as an Effective Countermeasure for Spaceflight-Induced Bone Loss and Renal Stone Formation	Bisphospho-nates	10	0	Initial inflight operations for this study scheduled to start in 2009
NASA Biological Specimen Repository	Repository	All U.S.OS	5	Crewmembers participating during Increment 18. Flight samples returned from Increment 16-17, recruitment continues for all future ISS missions
CSM harness SDTO: A New Harness For Use with Exercise Countermeasures - Validation of Improved Comfort and Loading with the Center for Space Medicine (CSM) Harness	Harness	5	0	New hardware has completed flight certification, initial inflight operations are scheduled to begin with Increment 20
Spinal Elongation and its Effects on Seated Height in a Microgravity Environment	Spinal	23	0	Selected for flight in 2008, 3 crewmembers successfully recruited for participation during the STS-128 mission scheduled for August 2009
Cardiac Atrophy and Diastolic Dysfunction During and After Long Duration Spaceflight: Functional Consequences for Orthostatic Intolerance, Exercise Capacity, and Risk of Cardiac Arrhythmias	Integrated Cardiovascular	12	0	Successfully recruited the first subjects for this investigation, flight operations are scheduled to begin with Increment 20 in 2009.

Current International Space Station Medical Project Flight Investigations

Investigator Title	Ops Title	Subjects		Status (as of December, 2008)
		Required	Completed	
Analyzing Interferometer for Ambient Air	ANITA	N/A	N/A	Inflight instrument verification and validation completed, flight hardware returned on ULF-2
Maximal Oxygen Uptake During Long Duration International Space Station Missions	VO2max	12	0	A new investigation selected for flight in 2008, 4 ISS long-duration crewmembers have agreed to participate with operations beginning in Increment 19-20
PVT Self Test on ISS	Reaction Self Test	24	0	Selected for flight in 2008, this investigation successfully recruited the first ISS crewmembers with operations starting with Increment 21-22
Physiological Factors Contributing to Changes in Post-Flight Functional Performance	FTT	13 Shuttle 13 ISS	0	Selected for flight in 2008, this investigation successfully recruited the first ISS and Shuttle crewmembers with operations currently planned for STS-128 and Increment 22
Human Factors Assessment of Vibration Effects on Visual Performance During Launch	Visual Performance	9 Shuttle	0	A new flight investigation that will provide data for the development of the Crew Exploration Vehicle. Multiple ISS missions are planned in 2009
Dietary Intake Can Predict and Protect Against Changes in Bone Metabolism during Spaceflight and Recovery	Pro K	16	0	An expanded version of the Nutrition investigation that is scheduled to begin crewmember recruitment in 2009
Intravenous Fluid Generation for Exploration Missions	IVGEN	N/A	N/A	Advanced technology will be tested and evaluated during this flight hardware demonstration planned for the STS-131 mission in 2010
A Comprehensive Characterization of Microorganisms and Allergens in Spacecraft Environment	SWAB	8 sessions	0	Air and surface sampling was completed on Increment 15, water sampling is scheduled to begin during Increment 19/20.

The ISSMP works with the Space Medicine Division, other HRP elements, and International Partners to return the data needed to address key risk areas. The ISSMP also develops and flight-validates a suite of integrated physical, pharmacological, and nutritional countermeasures designed to mitigate the effects of the spaceflight environment that could affect mission success or crew health and safety on exploration missions.

The ISSMP coordinates with the Space Station Payloads Office to streamline the processes for station usage, to increase the research output, and to maximize the sets of data that can be returned to guide future research to meet the objectives of the risk reduction program. For additional information visit: **http://humanresearch.jsc.nasa.gov/elements/issmp.asp**.

2008 Highlights

Periodic Fitness Evaluation Oxygen Uptake Measurements (PFE-OUM)

ISS crewmembers participating in the Periodic Fitness Evaluation with Oxygen Update Measurements (PFE-OUM).

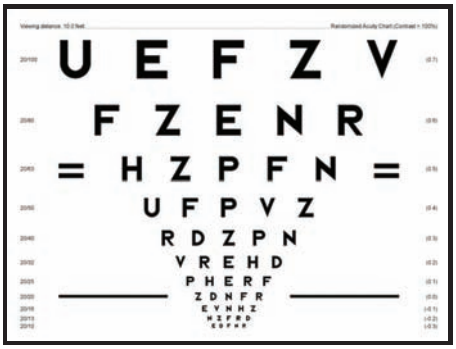
The Periodic Fitness Evaluation Oxygen Uptake Measurements study directly measured oxygen uptake during exercise tests conducted during the course of long-duration stays in space. During spaceflight, ISS crewmembers perform a submaximal monthly fitness evaluation. During the test, heart rate, and blood pressure are recorded during a prescribed exercise session allowing ground-based exercise physiologists and flight doctors to estimate crew health and fitness and accurately prescribe exercise countermeasures. With the addition of new equipment that measured oxygen uptake, cardiopulmonary measurements were made that more accurately reflected the physical fitness of the crew. The Periodic Fitness Evaluation Oxygen Uptake Measurements study was a collaborative effort between the European Space Agency and NASA. The final of 7 long-duration ISS crewmembers completed the pre- and inflight testing sessions in 2008 with the last postflight testing session performed in January 2009. Preliminary results indicate that the magnitude of the decline in aerobic fitness levels of ISS crewmembers was likely over-estimated in flights with no oxygen uptake measurements. However, confirmation of this finding awaits similar measurements to be performed on crewmembers performing maximal exercise.

Analyzing Interferometer for Ambient Air (ANITA)

Flight engineer, Clay Anderson, using the sampling pump and 2.5 liter gas sample bag for the ANITA experiment in Node 1/Unity

ANITA is a joint project between NASA and European Space Agency. The European Space Agency provided the ANITA instrument, while NASA provided accessory equipment and payload integration support. ANITA is a Fourier-transform-infrared technology-based trace-gas monitoring system that was tested for accuracy and reliability as a potential next generation atmospheric trace gas monitoring system for ISS. The instrument is calibrated to simultaneously monitor 32 gaseous contaminants at low parts per million levels in the cabin atmosphere without changing the physical or chemical properties of the gas sample. Its quasi on-line, fast time resolution allows air quality to be analyzed. The ANITA payload was launched on STS-118 in August 2007 and subsequently installed in an EXPRESS rack on ISS. After 10 months of nearly continuous operation on board ISS, ANITA was de-activated and stowed in August 2008 in preparation for being returned on STS-126. ANITA provided valuable data to the environmental factors team regarding ISS air quality as well as provided lessons learned for use of the Fourier-transform-infrared technology instrument for potential next generation trace gas monitoring.

ISSMP Support for Space Flight Participants



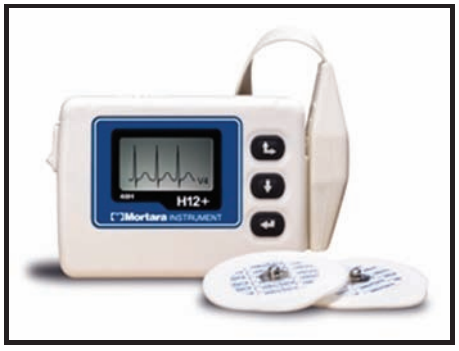
Eye chart used during ISS missions to assess changes in distance vision.

Through cooperative NASA Space Act Agreements, 2 spaceflight participants completed missions to ISS in 2008, including South Korean astronaut So-yeon Yi and American businessman, Richard Garriott. An agency level agreement was established between the Korean Aerospace Research Institute and NASA to document the first cooperative research between the 2 agencies.

During their 10-day missions, both spaceflight participants volunteered in NASA human life sciences studies. While both participated in the Sleep study, Mr. Garriott also completed the Integrated Immune and Visual Acuity investigations. During the Sleep study, participants wore a special Actiwatch device to monitor their sleep-wake patterns and light exposure while on board ISS, as well as completed a daily sleep log. The Integrated Immune investigation assessed the clinical risks resulting from the adverse effects of spaceflight on the human immune system and the potential effect on increased health risks. A main objective of the Visual Acuity study was to assess possible changes in vision due to fluid changes in the body and increased pressure in the eyes.

Training and preflight data collection for these studies was supported by the Project and conducted both at the Johnson Space Center and in Star City, Russia. Inflight operations were designed to make use of hardware and supplies already on board the ISS. Data from these studies have been returned to the investigators and analysis is in progress.

Holter Monitor 2



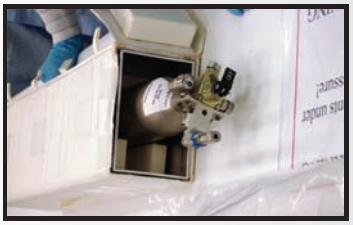
Holter Monitor 2

A next generation Holter Monitor 2 was delivered by the Ames Research Center and launched to ISS on STS-126 in November 2008. This Holter monitor is a flight-modified commercial-off-the-shelf ambulatory electrocardiogram device (Mortara H12 device) that provides 24 hours of 8 or 12-lead electrocardiogram data and records data using only 1 AA battery. The monitor measures the electrical activity of crewmembers' hearts and includes options for a variety of sampling rates and lead cable configurations depending on specific experiment requirements. The unit provides full graphic display to preview electrocardiogram waveforms during setup and is capable of high resolution pacemaker detection. The monitor was used successfully on orbit for the first data collection sessions on Increment 18 for the Cardiovascular Control on ISS experiment. The electrogram data are collected onto a Compact Flash data card, transferred to the ISSMP computer and downlinked for distribution to the investigators.

Pressurized Inhalation Gas Cylinder

The first pressurized inhalation gas bottles were launched on STS-126 in November 2008. The pressurized-inhalation-gas cylinder is designed to deliver breathing gases on-orbit for use in hardware calibration and in experiments. The hardware provides a single portable gas bottle in a protected case

that will be used with ISSMP experiments and is designed to interface with the European Space Agency-designed portable pulmonary function system, which will be launched to ISS on a future flight. The initial use of this hardware is scheduled in support of the NASA investigation "Evaluation of Maximal Oxygen Uptake and Submaximal Estimates of VO2max before, during, and after Long-Duration International Space Station Missions" with ISS Increment 19–20 crew. The pressurized-inhalation-gas cylinder was designed, built, and flight certified at the Johnson Space Center.



Flight hardware bench review prior to launch of the pressurized-inhalation-gas cylinder to ISS.

Muscle Atrophy Research and Exercise System (MARES)

Ground-based operations of the MARES hardware.

The muscle atrophy research and exercise system is a joint European Space Agency and NASA physiological research facility that will be used on ISS to carry out research on musculoskeletal, biomechanical, and neuromuscular human physiology. The MARES instrument is provided by the European Space Agency, while NASA is integrating the device into a rack for launch and on-orbit operations. In 2008, a critical design review was held for the MARES and the training model was delivered to the Johnson Space Center. The MARES flight model is scheduled to be delivered in early 2009 to support launching to ISS on STS-131.

NASA Biological Specimen Repository (NBSR)

The NASA Biological Specimen Repository was established in 2008. A "repository" is a storage bank that is used to maintain biological specimens over extended periods of time, under well-controlled conditions, for future use. This facility has been developed to archive biosamples and associated data from long-duration spaceflight crewmembers for use as a resource for future spaceflight-related research.

Flight hardware used to collect blood samples during ISS missions.

The ISS provides a platform to investigate the effects of microgravity on human physiology prior to lunar and exploration class missions. The storage of crewmember samples from many different ISS flights in a single repository will be a valuable resource with which researchers can validate clinical hypotheses, study spaceflight related changes, and investigate physiological markers. Biological specimens provide a means for investigating the physiological responses to spaceflight. The sample collections for this protocol focus on blood and urine samples. Multiple specimens and data from ISS crewmember are collected, processed and archived from the pre, in, and postflight phases of ISS missions. Storage of samples at ultra-low temperatures ensures long-term stability and sample integrity. During 2008, 7 ISS crewmembers collected human biological samples for storage in the repository for future research activities. The collection of samples is continuing in 2009 and crewmember participation is anticipated until the end of the use of ISS.

Space Radiation Element

The goal of the Space Radiation Element (SRE) is to ensure that the crews can safely live and work in the space radiation environment without exceeding the acceptable radiation risks. Space radiation differs from radiation encountered on Earth[1] and the health risks from space radiation may include an increased incidence of cancer, acute radiation sickness, early and late degenerative tissue damage, and central nervous system damage. Space radiation risks have clinically relevant implications for the lifetime of the crew. For this reason, space radiation studies rely on biomedical and radiation physics expertise to provide:

- Recommendations to space radiation permissible exposure limits for exploration missions
- Radiobiological data, projection models, and computational tools to assess and project crew risk of cancer, central nervous system, degenerative risks, and acute radiation syndrome from space radiation
- Computational tools and models to assess vehicle design for radiation protection
- Assessment of technology developments for monitoring radiation exposure and recommendations on technologies to be used operationally
- Uncertainty reductions to enable radiation protection design and crew constraints for lunar and Mars missions
- Assessments of the effectiveness and development of physical or biological countermeasures

The results of space radiation studies contribute to the exploration initiative by providing the scientific basis to accurately project and mitigate health risks. The radiobiological and physics research guide and support risk assessment and protection strategies. The results will also provide tools for evaluating shielding recommendations for habitats and vehicles and requirements for storm shelter and early warning systems for solar particle events. To read more about the SRE, please visit: **http://humanresearch.jsc.nasa.gov/elements/radiation.asp**.

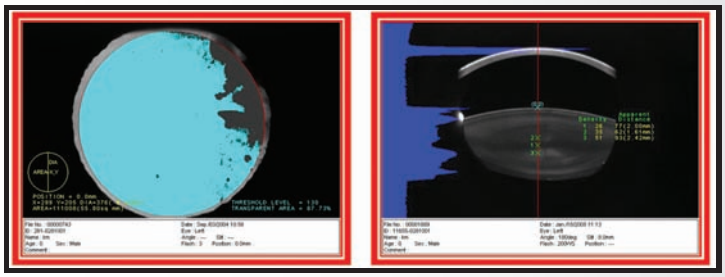
Space radiation poses acute and lifetime risks to astronauts such as cancer, central nervous system detriments, degenerative diseases such as heart disease and cataracts, and radiation sickness. Cancer risks poses the largest challenge for exploration with the uncertainties in cancer risk projection having large impacts on lunar and Mars mission designs, limiting NASA's ability to adjust mitigation measures such as shielding and biological countermeasures. For the central nervous system and degenerative risks, there are uncertainties in the dose thresholds, latency, and clinical significance of the diseases that may occur. Acute radiation sickness is possible if adequate operational procedures and shielding are not provided and research is needed to optimize radiation protection practices in these areas.

1The primary sources of radiation in space are galactic cosmic rays, which consist of protons and electrons trapped in Earth's magnetic field and solar particle events. Galactic cosmic rays permeate interplanetary space and include high ionizing energy particles. They cause damage at the cellular and tissue levels is unlike the damage caused by the terrestrial radiation such as x-rays or gamma rays because of the significantly higher ionizing power, greater potential for radiation-induced damage, and greater penetration power of high ionizing energy particles.

2008 Highlights

Research Highlights

A major SRE research accomplishment includes a publication in the prestigious journal, Nature Reviews Cancer, summarizing the current state-of-knowledge of space radiation cancer risks and approaches to mitigation. The SRE-funded research showed that the risks of solid cancer from cosmic ray heavy ions may be higher than previously estimated. The research included new results with energetic iron ions on liver tumor risks and genomic instability in two and three-dimensional human mammary epithelial cell culture. New findings in genetic sensitivity revealed that DNA repair regulating genes, including the gene mutated in ataxia telangiectasia patients, and the product of the gene mutated in the Nijmegen breakage syndrome, are less sensitive to cosmic rays when compared to gamma-rays. Assumptions on genetic sensitivity reported at high doses used in cancer therapy may not apply at the dose levels of space missions. The NASA Study of Cataracts in Astronauts, using state-of-the-art methods, documented the increase incidence of cataracts in astronauts with higher space doses.



NASA Study of Cataracts in Astronauts study images of cataracts. The left-side panel digital photograph is a binarized retro-image of lens with cataract. Blue areas show region of a clear lens, and black areas show region opaque or with cataract. In the right-side panel, the dark blue graph on left side of the slit image is an objectively determined histogram of image density at each point. This study has the ability to detect minute cataracts (<1 % area opaque) and follow their progression with time and is correlating growth-rates with galactic cosmic rays exposures on past space missions.

Workshops and Outreach

The 19th Annual NASA Space Radiation Investigators' Workshop was held in late June in Philadelphia, PA. The workshop offered the opportunity for NASA-funded investigators to share the results of their work and to explore new directions of research to benefit the health of space explorers. The workshop included invited talks, plenary talks, poster sessions, and awards for young investigators' posters.

As development of the next generation of radiation researchers, 15 students were selected to attend the NASA Space Radiation Summer School held at Brookhaven National Laboratory in June. The students and 2 auditors included graduate students and faculty in biology and physics, foreign and domestic students; 31 lecturers worked with the course director from the Lawrence Berkeley National Laboratory.

The SRE established a collaborative website at the Universities Space Research Association (USRA) (**http://spaceradiation.usra.edu**) for the space radiation biology community that contains quarterly newsletters, meeting and research announcements, and a space radiation encyclopedia fashioned after the WIKI model called THREE (The Hazards Radiation Environments Encyclopedia).

Co-Operative Agreements

The SRE continued its co-operative agreement with the Loma Linda University proton treatment center for beam time usage. The NSBRI has a co-operative agreement with NASA and the SRE collaborated with NSBRI Radiation Effects Team to focus experimental research on acute radiation risks. In February, NSBRI released a solicitation—Ground Base Studies on Acute Radiation Effects—focused on the assessment of acute radiation risks and countermeasures for solar particle events. The award was made in August.

Collaborations

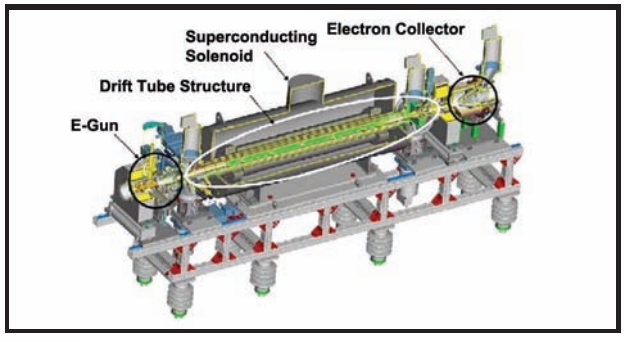
The SRE collaborates with the Department of Energy's (DoE) Office of Science in understanding the risks to humans from exposures to low doses or low fluences of ionizing radiation. In March, DoE released a joint solicitation—Low Dose Radiation Research Program – Basic Biology and Modeling—focused on elucidating molecular mechanisms and pathways involved in normal radiobiological responses to low dose exposures. The SRE also collaborates with international entities such as the European, Italian, Russian and Japanese Space Agencies, the European Union Radiobiology Research Program, and is participating with the International Council on Radiation Protection, on recommendations for radiation protection in space.

Reviews

The SRE supported the National Research Council review of NASA's overall radiation programs. In April, the National Research Council released the report "Managing Space Radiation Risk in the New Era of Space Exploration". The Executive Summary listed 10 prioritized recommendations for technology investments that are consistent with the SRE approach.

Facilities

The NASA Space Radiation Laboratory at the Brookhaven National Lab continues to be a world class facility enabling critical space radiation scientific research and significant upgrades are being implemented. To develop accurate estimates of radiation-associated risks to human beings in space and identify countermeasures for reducing those risks, NASA researchers participated in 3 campaigns of several weeks in duration at NASA Space Radiation Laboratory during 2008. During these campaigns, scientists irradiated a variety of biological specimens, tissues, and cells during a total of ~1250 hours of beam time. The research yielded over 40 peer-reviewed scientific publications.



Computer-aided design view of electron beam ion source.

Planning for dose-rate studies at NASA Space Radiation Laboratory, several key upgrades were designed and tested during 2008: the solar particle event simulation and large beam upgrade will be available to NASA researchers in 2009. As well, the electron beam ion source, being developed in

collaboration with DoE's Office of Nuclear Physics, met several key construction milestones in 2008. Upon completion in 2010, the electron beam ion source will offer a larger array of ion species at higher beam intensities than presently available, with greater operational flexibility and potential for real-time galactic cosmic rays simulation. To read more about the NASA Space Radiation Laboratory visit: **http://spaceflight.nasa.gov/shuttle/support/researching/radiation/**.

Human Health Countermeasures (HHC) Element

NASA uses the term “countermeasures” to describe the procedures, medications, exercise, and other strategies that help to keep astronauts healthy and productive during space travel and return to Earth. The HHC Element is responsible for understanding the physiological effects of spaceflight and developing countermeasure strategies and procedures. HHC Element investigators use a number of settings to research and test potential countermeasures. Optimally, all countermeasures will eventually be validated in flight or on the lunar surface during operations. However, prior to flight-testing, many candidate countermeasures and technologies are assessed using flight analog environments. Example analog settings include: bed rest, undersea habitats, Antarctica outposts, and other environments that simulate some aspect of spaceflight.

The goal of the HHC Element is to develop and validate an integrated suite of countermeasures for exploration missions. These countermeasures will maintain human physiological and performance capabilities so that crews can perform all required duties during the many phases of an exploration mission. These phases include time in microgravity, transitions from Earth’s 1-gravity environment to low-Earth orbit, to the 1/6 gravity of the Moon, back into space, and return to Earth. Preflight, postflight, and inflight activities are also encompassed. Preflight countermeasures involve limiting exposure to contagious diseases, physical conditioning, and physiological adaptation training. Inflight countermeasures include exercise, nutritional, pharmacological, and physical (gravity suits, suit design, prebreathe) activities. Postflight treatments target rehabilitation strategies.

Major Accomplishments

The diverse HHC Element comprises 5 projects that address exercise, non-exercise, and extravehicular activity (EVA) countermeasures as well as flight analog facilities and computational modeling to help test and integrate potential countermeasures before their actual flight verification.

Major accomplishments are described by each project:

- Exercise Countermeasures Project
- EVA Physiology, Systems & Performance Project
- Flight Analogs Project
- Non-Exercise Physiological Countermeasures Project
- Digital Astronaut Project

For more information, please visit the HHC Element’s website at **http://hacd.jsc.nasa.gov/projects/hhc.cfm**.

Exercise Countermeasures Project (ECP)

The ECP provides exercise hardware and monitoring equipment in addition to the exercise prescriptions to optimize health and performance of flight crews for exploration missions. The project uses studies from spaceflight analogs, the Space Shuttle, and ISS to quantify program risks and identify improved exercise countermeasures.

2008 Highlights

Functional Task Test

A subject performs the hatch opening/torque generation test during a pilot study for the Functional Task Test.

Physiological adaptations to spaceflight including cardiovascular, neuromuscular and sensorimotor maladies are well documented. However, the consequences of these physiological adaptations to astronaut performance of functional tasks are poorly understood. To address this, the ECP is sponsoring a multidisciplinary study referred to as the Functional Task Test to examine the role of postflight physiological alterations on the ability of astronauts to perform functionally relevant tasks. Functional tasks were developed based on common mission tasks that will need to be performed during exploration missions (e.g., ladder climb, hatch opening, and construction activities). Astronauts' performance of these functional tasks will be measured before and after short-duration Shuttle flights and long-duration flights aboard ISS. These results will indicate the types of activities that are expected to be impacted during future planetary exploration. A battery of cardiovascular, neuromuscular, and sensorimotor physiological tests will be performed in conjunction with the functional tests. The determination of which physiological decrements best map to changes in functional performance will allow for targeted countermeasures to be developed for the protection of the physiological parameters that contribute most to the astronauts' ability to perform mission tasks. These targeted countermeasures are aimed at improving mission success in the most efficient manner. During 2008, the functional task test investigation was officially selected for flight by the HRP. The Functional Task Test research team completed 2 pilot studies during 2008 to refine the flight protocol. One study was a test-retest reliability examination of the functional task simulations. A second pilot study was performed to develop new physiological measures of skeletal muscle performance including analyses of muscle power and central activation. Both short and long-duration postflight testing will begin during 2009.

Advanced Exercise Concepts for Exploration

Mass, volume, and power will all be at a premium during future lunar exploration. Effective exercise countermeasures approaches developed using ISS and flight analogs such as bed rest will need to be transferred to small, efficient, multi-purpose exercise devices that can be used during Constellation missions. Exploration class hardware will be needed for the Orion and Altair vehicles that will take astronauts back to the Moon, as well as during surface missions that may last up to 6 months. The Lunar Electric Rover is a pressurized lunar rover concept that would allow astronauts to traverse the

lunar surface in the comfort of a shirt-sleeve environment. These rovers are designed to accommodate multi-day traverses away from the lander and/or outpost and may even be used as the primary habitation elements. A significant portion of crew time may, therefore, be spent in the rovers, making access to robust exercise countermeasures an important feature in their design. The ECP at the Johnson Space Center and Glenn Research Center partnered with the Lunar Electric Rover project to produce a multifunctional cycle ergometer-resistance exercise device for the rover. The prototype device also includes the capability to charge batteries on board the vehicle while exercise is being performed, which would be a valuable function during lunar missions. The prototype device, which weighs less than 40 pounds, was evaluated for logistics during simulated lunar exploration missions as part of the 2008 Desert Research and Technology Studies campaign. The ECP and the EVA Physiology Systems & Performance Project plan for continued evaluation and improvement of the device during 2009. Such a multifunctional device could represent an invaluable exercise countermeasure for the return to the Moon.

The Lunar Electric Rover exercise device prototype is installed in the rover in the cycle ergometer configuration.

Treadmill Harness

Treadmill running is a staple exercise countermeasure on ISS. Treadmill exercise provides protective loading to bones and postural muscles, and offers an aerobic stimulus to crewmembers during long-duration missions on ISS. In a weightless environment, treadmill running is only possible with an artificial loading system to keep the runners feet in contact with the treadmill belt. The loading system that is used today employs a series of bungee cords attached to a harness worn by the crewmember. Unfortunately, the current ISS treadmill harness has been reported to cause chafing and abrasions in crewmembers. The discomfort associated with the current harness contributes to suboptimal loading during treadmill exercise. During 2008, the ECP team at the Glenn Research Center completed development and production of a new flight-quality harness that is designed to improve both fit and function. This new harness and the current ISS treadmill harness will be evaluated side-by-side for comfort and loading in flight aboard ISS starting in late September 2009. During the qualitative evaluation of comfort and fit, the harnesses will also be instrumented with load-sensing transducers to understand the total subject loading and the load distribution on the shoulders and hips during treadmill use. This information will be used to prove out the new harness design for potential operational use.

The treadmill harness features custom sizing for both male and female crewmembers, removable lumbar padding, and biocidal fabric.

Muscle Workshop

During June of 2008, the ECP sponsored a Skeletal Muscle Workshop. The goal of the workshop was to include members of the external academic research community in the process of developing research strategies to address the Integrated Research Plan Risk of Impaired Performance due to Reduced Muscle Mass, Strength and Endurance. The panel was presented with the state of exercise countermeasures aboard ISS and Constellation's vision of future planetary exploration. The panel made informed recommendations for research to be performed by NASA to develop exercise countermeasures to preserve muscle mass and function during exploration. The panel concurred that there is sufficient evidence from ground-based flight analog research to support using a resistance exercise paradigm of higher intensity and reduced volume and frequency in flight. The panel recommended that a high intensity regimen be validated with a flight study aboard ISS. This high-priority recommendation was the impetus for a follow-up ISS Exercise Prescription Workshop that occurred in October of 2008. The ISS Exercise Prescription Workshop was a collaborative effort to generate guidelines for an exercise protocol to protect against the adverse effects of long-duration weightlessness on muscle mass and function, bone mineral density and architecture, and aerobic capacity while using a minimal amount of crew time. This effort was conducted by external academic research partners, members of the ECP, the HHC Element, Medical Operations, and the Astronaut Strength, Conditioning and Rehabilitation group. A flight study investigating an experimental exercise countermeasures protocol based on ISS Exercise Prescription Workshop guidelines will undergo external merit review in 2009 and is targeted for flight in early 2010.

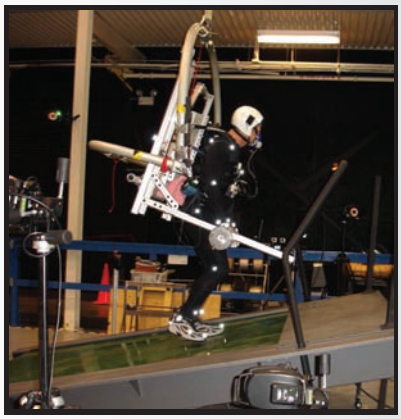
EVA Physiology, Systems & Performance (EPSP) Project

As the extravehicular-activities (EVA) suit systems and operational plans for future exploration missions evolve, the EPSP Project continues working with other HRP projects and Constellation to execute a series of prospective, integrated human performance tests using multiple analog environments. These tests are providing objective data to enable refinement of human health, safety, and performance-related requirements for exploration EVA suits, integrated suit systems, and mission operational concepts. In addition, the project is working to develop models and requirements for enhanced occupant protection during nominal and off-nominal Orion landings.

2008 Highlights

Human Performance Data Collection Series

During 2008, integrated tests continued in several reduced gravity analog environments to build upon our understanding of how factors such as suit weight, mass, center of gravity, pressure, and kinematics affect human performance while working in an EVA suit. Data analyses are nearly complete for Integrated Suit Test 2, which assessed the impact of these factors on human performance while subjects completed a sequence of simulated exploration and construction tasks at the partial gravity simulator facility. Initial findings indicate that suit weight and the type and distribution of work tasks can have a large impact on human performance during EVA.



Inclined walking during unsuited portion of Integrated Suit Test 3 at the partial gravity simulator facility. Subject is wearing reconfigurable rig that allows for adjustments to center of gravity.

Two studies initiated in 2008 will enable better understanding of the specific roles of center-of-gravity and suit mass during performance of ambulation and exploration tasks in simulated lunar gravity. Earlier EPSP tests characterized performance effects of 6 potential EVA suit center-of-gravity locations and identified a range of desirable center-of-gravity locations based upon subjective crewmember ratings. The current tests are evaluating subsets of these center-of-gravity locations for their respective effects on unsuited and suited performance. Integrated Suit Test 3, being conducted at the partial gravity simulator facility, evaluates effects of center-of-gravity and suit mass while subjects ambulate on a level and inclined treadmill, complete representative exploration tasks and stand still on a force platform. Unsuited portions of the test were completed in 2008, and the remaining portions including suited trials are planned for mid-2009. The Integrated Parabolic Flight Test, begun in December, further evaluates a subset of the Integrated Suit Test-3 center-of-gravity configurations and the contribution of suit mass to human performance in flight-simulated lunar gravity. This test will be used to validate data collected at the partial gravity simulator facility and to perform additional, mass-matched tests that are not possible on the partial gravity simulator due to limitations in its lift capabilities. Biomechanical and subjective parameters are measured while crewmembers perform ambulation and exploration tasks both unsuited and while wearing the Mark III Advanced Space Suit Technology Demonstrator EVA suit.

Ambulation across force plates during 20-foot traverse aboard NASA's C-9 reduced gravity aircraft.

Performance of simulated exploration tasks at lunar gravity aboard the C-9 aircraft.

NASA Haughton-Mars Project

The 2008 Walkback test at the NASA Haughton-Mars crater site, along one of last year's 10 km routes.

The 2007 NASA Haughton-Mars Project Walkback experiment established that lunar-like terrain significantly increased a crewmember's metabolic rate when compared to speed and grade-matched treadmill-control trials. To follow-up these results, the EPSP Project conducted a 2008 study to determine whether stride frequency and foot-ground contact time are higher while ambulating on lunar-like terrain as compared to speed and grade-matched treadmill-control trials. Subjects performed a series of short (<5 min) traverses across representative terrains taken from the 2007 Haughton-Mars Project test series while wearing accelerometers, a heart-rate monitor, and a GPS data collection system. Each subject will return to the Johnson Space Center to complete a speed and grade-matched trial on the treadmill. Developing an understanding of the differences between a controlled treadmill environment and an operationally relevant lunar-like environment will allow for generalized correction factors when interpreting study results and creating evidence based requirements.

Flight Analogs Project (FAP)

The FAP supports a variety of investigations using ground-based, bed rest analogs. Bed rest is a well established spaceflight analog to study changes in physiological function associated with reduced gravity and spaceflight. A battery of biomedical tests, called standard measures, are conducted on each subject to assess immune function, nutritional status, cognitive function, cardiovascular responses, exercise responses, neurological function, and bone physiology before, during, and after bed rest.

In addition, preparations were made for a future study to examine treadmill exercise as a countermeasure to bone loss experienced during bed rest. This study will use the stand-alone zero-gravity locomotion simulator. In this device, subjects can lie horizontally while exercising on the treadmill. By applying an exercise load equivalent to the subject's prebed rest daily activities, investigators hope to prevent bone loss that occurs during bed rest. It is anticipated that this study will begin in 2009.

Flight Analogs Project Studies

	C5 Vibration Simulation	C3 Gender Differences	LAFS Lunar Analog Feasibility Study	DBLS Exercise Countermeasure
Study Question	Can mechanical stimulation inhibit bone loss during spaceflight?	What causes the difference in orthostatic hypotension between men and women post flight?	Is the lunar bed rest model a feasible simulation of the affects of lunar gravity on the human body?	Can treadmill exercise that is equivalent to pre-bed rest activity inhibit bone loss experienced in bed rest?
Study Duration	90-day bed rest	90-day bed rest	6-day bed rest	84-day bed rest
Subjects Needed	18	34	23	12
Study Completed	18	15	16	0
Study Status	Completed	Ongoing	Ongoing	Pending start

2008 Highlights

C3 Gender Differences

During 2008, the 6-degree head-down tilt, 90-day bed rest studies (C3 Gender Differences) continued. This bed rest model simulates the physiological affects of microgravity on the human body. Studies using this model include cardiovascular investigations to examine gender differences in orthostatic tolerance that are observed postflight in astronauts. To accomplish this, scientists evaluate gender differences in arterial pressure control in conjunction with the vascular responsiveness of upper and lower extremities before and after 90 days of bed rest.

Lunar Bed Rest Analog Feasibility Study

In the same way that 6-degree head-down tilt bed rest is analogous to the microgravity of spaceflight; lunar gravity can also be simulated on Earth using a long-duration bed rest model. To this end, the FAP initiated development of a lunar bed rest model. The lunar gravity simulator was completed and added to the suite of analog environments offered at the Flight Analogs Research Unit, located at the University of Texas Medical Branch, General Clinical Research Center, in Galveston, TX. Modeling lunar gravity, or 1/6 of Earth's gravity, is accomplished by tilting the body at 9.5-degree head-up tilt. In this position, 1/6 of the subject's body weight is applied at the feet. The FAP's lunar-gravity simulator allows test subjects to sit and stand while at a 9.5-degree angle. Also, the lunar gravity simulator allows test subjects to walk and jump in an effort to simulate the expected activities of astronauts on the Moon. Feasibility studies were conducted to verify the 1/6-gravitational loading along the long axis of the body and to examine subject tolerance of this model during a 6-day bed rest period. Once the feasibility studies are complete, a 60-day pilot study is planned to examine the physiological changes that occur in this model. Data from the lunar pilot study will be verified against predictions from the Digital Astronaut Project. Following this, the lunar gravity simulator will be used by investigators to test and develop countermeasures to mitigate the effects that 1/6-gravity may have on astronauts living on the Moon for extended durations.

Hurricane Ike Evacuation and Recovery Efforts

In September of 2008, Galveston Island and FAP were challenged by Hurricane Ike. The research unit is susceptible to hurricanes and tropical storms that make landfall along the western coast of the Gulf of Mexico. With Hurricane Ike rapidly approaching Galveston, all FAP studies were suspended and the 8 research subjects that were actively enrolled were all safely evacuated from Galveston prior to Hurricane Ike's arrival. Within 7 weeks after the hurricane, the FAP worked successfully to restart the 6-day lunar analog feasibility study. Restart of long-duration bed rest studies is planned for February 2009.

Non-Exercise Physiological Countermeasures (NxPCM) Project

The NxPCM Project addresses cardiovascular, immunological, skeletal (bone), nutritional, pharmacological, and neurovestibular (sensorimotor) physiology in an operationally-driven research program seeking to understand and, if possible, mitigate spaceflight human health and performance issues. During 2008, our research portfolio contained 39 ongoing flight and ground research studies performed by intramural and extramural investigators across the 6 physiological disciplines.

2008 Highlights

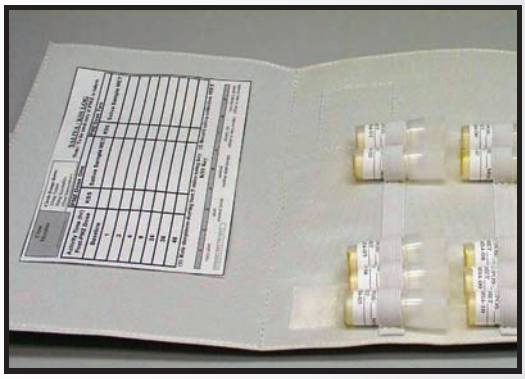
Bioavailability and Performance Effects of Promethazine during Space Flight (PMZ)

Inflight operations for this investigation were successfully completed in 2008 following the STS-122 mission. This study collected data from 14 short-duration subjects (9 subjects and 5 control subjects). Promethazine is a medication that Shuttle and ISS crewmembers take to combat space motion

sickness during their first few days on-orbit. Anecdotal reports from crewmembers indicate that when promethazine is taken in space it acts differently in the body than it does when administered on Earth. This study helped researchers understand the absorption rate, performance effects, and side-effects of this medication in the spaceflight environment and are essential for determining optimal dosage and route of administration of promethazine in flight.

Results of this study are critical for evidence-based medical practice of all exploration programs (ISS, Moon, and Mars missions) and are required for ensuring crew health and optimizing medical standards. The specific application of the results is for the treatment of inflight space motion sickness and of nausea associated with postflight landing.

Understanding inflight drug interactions will be important on longer-duration missions as pharmaceuticals are considered to combat illnesses along with muscle and bone loss. The results returned from the Shuttle astronauts will lay the foundation for future, long-duration pharmaceutical studies that could lead to novel countermeasures necessary for exploration missions.



Inflight sample vials for the collection of saliva used to measure the absorption and availability of promethazine in the body.

Nutrition Supplemental Medical Objective (SMO)

During 2008 the principal investigator from the Nutritional Biochemistry Laboratory presented data from the first 3 crewmembers participating in the study entitled “Nutritional Status Assessment”. Data indicates vitamin D levels are being maintained at preflight levels with recommended supplementation at 800 IU/d (average intake of 529 ± 123 IU/d). Collagen crosslink excretion during ISS missions indicates the same 100% to 150% increase in excretion of bone resorption markers as observed in Skylab and Mir crews and a decreasing trend in total antioxidant capacity in ISS crewmembers. The laboratory received additional samples returned on STS-126 in November and have completed data collection on at least 5 subjects with an additional 7 subjects anticipated in 2009. An additional 12 subjects were added to the study to allow the analysis of individual effects (countermeasures - pharmacological, exercise, dietary; gender differences; etc.) to be more detailed, and possibly better identify gender differences among astronauts.

Astronaut Sunita Williams storing nutrition samples collected in flight in the Minus Eighty Laboratory Freezer for ISS.

VIBE

In early 2008, the project held a review to discuss the results of the bed rest study entitled “Retention of Skeletal Musculature & Postural Status With a Non-Invasive, Extremely Low Level Mechanical Signal: A Ground Based Evaluation of Efficacy” where the principal investigator presented his current study findings from this study’s campaigns, all conducted with subjects maintained at 6-degree head-down tilt to simulate the microgravity environment. Supplementary data collected by the Johnson Space

Center's Bone, Cardiovascular, Exercise, and Neurosciences laboratories also were presented for discussion. Consensus of the NASA review panel was that benefits of this study were not operationally significant as a countermeasure to bone loss. The principal investigator concurred that the data showed that minimal benefit to bone retention was measured. The study is in close-out and all data analysis is expected to be completed during 2009.

Subject receiving VIBE treatment during a bed rest study.

Integrated Immune

Inflight blood collection kit used for the Integrated Immune investigation.

During 2008, the Integrated Immune team successfully returned study samples via the Soyuz vehicle and remained within the technical constraints of the study. All Integrated Immune samples must be maintained within a pre-determined temperature range and delivered to laboratory support staff for processing within a defined timeframe. This is because live cells are being returned for culture assays, meaning sample viability is critical. To date, samples have been returned on 2 Soyuz landings. Onboard the 15S Soyuz, returning the Increment-16 crew, inflight samples from 2 crewmembers were returned. Onboard the 16S Soyuz, returning the Increment-17 crew, an additional 2 inflight samples were returned. For both missions, samples were retrieved from the Soyuz, transported from Kazakhstan to Russia, and delivered to support staff at Star City within the required temperature and time limits. Samples were processed at Star City and returned to the Johnson Space Center for analysis. The Integrated Immune inflight hardware was specifically designed to accommodate returning samples on board either the Shuttle or Soyuz vehicles. Continued sample return via the Shuttle and Soyuz is expected during 2009.

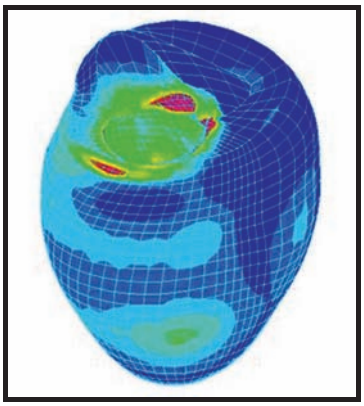
Midodrine

In August of 2008 the Midodrine as a Countermeasure for Post-Spaceflight Orthostatic Intolerance study was evaluated at the Human Systems Risk Board where it was decided that the potential side-effects and interactions with other medications outweighed the benefit of the use of midodrine as a countermeasure. The study found that midodrine was effective at mitigating orthostatic hypotension, but adverse reactions (involuntary movement, anxiety and aggressive behavior) were identified when taken in combination with promethazine, which is widely used to prevent motion sickness. Also, midodrine was identified to lengthen the QTc interval causing flight surgeons to prevent the administration of midodrine if the subject's QTc interval was greater than 0.45 seconds in a male or 0.47 seconds in a female, prior to pill ingestion. These issues, in addition to the potential of mechanical countermeasures that are being evaluated, led to the recommendation that this study be de-selected. Formal de-selection was received in November 2008 and personnel are closing-out the investigation.

Digital Astronaut (DA) Project

Predicting the effects of space flight on the human body is challenging. Longer, more physically demanding missions necessitate a better understanding of human physiology during space flight to establish health and safety requirements for these new missions. The DA Project is working to develop a detailed computer model of the entire human body. This model will be used to predict the effects of spaceflight on each body system. Researchers started developing detailed models of bone loss, kidney stone formation, and the heart. The computer model of the human body will be useful to the medical community to aid in understanding disease and lead to improvements in pharmaceuticals, surgical procedures, and treatments.

2008 Highlights



Three-dimensional model of the human heart.

As the HRP began to develop protocols for lunar bed rest studies, DA Project personnel used portions of the Digital Astronaut code to predict the optimal protocol. Based on a purely gravitational level analysis, a 10-degree head-up tilt was indicated for the skeletal system. Based on an analysis of the fluid distribution, a 2-degree head-up tilt would be indicated for the cardiovascular system. Project simulations suggested that using Jobst® compression stockings in conjunction with a 10-degree head-up tilt would provide reasonable fidelity to lunar conditions for both systems. The DA predicted a 6% loss in plasma volume during such studies; results from test subjects showed a 7.5% loss. Follow-on data from a 60-day pilot study will be used to refine the model.

Analytic experts completed a preliminary analytic formulation of bone turnover at the cellular level. To successfully understand the mechanisms behind spaceflight-induced bone loss, a simulation of bone turnover at that level was needed. A review by bone discipline experts at the Johnson Space Center resulted in the incorporation of refinements and recommendations for further development.

The renal stone formation and transport models were completed and validated against physical science and clinical data. The model is based on crystal growth and fluid physics transport.

The project initiated plans to guide open source code availability and validation. As part of that effort, the code was converted to XML and work began on an editor to facilitate development and incorporation external modules.

Exploration Medical Capability (ExMC) Element

During missions to the Moon or to Mars, the crew will need medical capabilities to diagnose and treat injury or disease as well as maintain crew health. The ExMC Element develops medical technologies, data handling capabilities, and clinical procedures for different levels of care during space missions. The ExMC Element develops medical technologies for inflight diagnosis and treatment as well as data systems that protect patient private data, aid in the diagnosis of medical conditions, and act as a repository of relevant NASA life sciences experimental studies. To minimize the medical risks to crew health the physicians and scientists in the ExMC Element develop models to quantify the probability of medical events occurring during a mission. They define procedures to treat an ill or injured crewmember who does not have access to an emergency room and who must be cared for in a microgravity environment where both liquids and solids behave differently than on Earth.

Human exploration of the Moon and Mars presents significant, new challenges to crew health:

- Hazards created by traversing lunar or planetary surfaces
- Effects of exposure to a number of different gravity environments
- Limitations on communications with ground-based personnel for consultation and diagnostic assistance for medical events

Providing health care capabilities that overcome these challenges requires new health care systems, procedures, and technologies to ensure the safety and success of exploration missions. In addition, exploration levies new requirements on data management. The ExMC Element is developing new approaches to catalog information so that it can be queried and analyzed. New methods are needed to train medical personnel who may not have access to experts for consultations. Developing these capabilities are the goals of the ExMC Element.

2008 Highlights

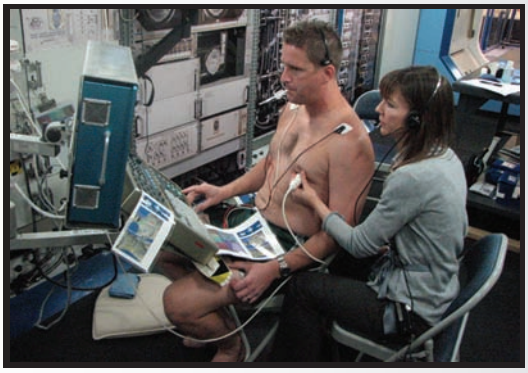
Validation of On-Orbit Methodology for the Assessment of Cardiac Function and Changes in the Circulating Volume Using "Braslet-M" Occlusion Cuffs (Braslet)

The study "Validation of On-Orbit Methodology for the Assessment of Cardiac Function and Changes in the Circulating Volume Using Ultrasound and Braslet-M Occlusion Cuffs", station development test objective (SDTO) 17011 (Braslet) is a collaborative effort between the NASA and the Russian Federal Space Agency. The goal of this investigation is to establish an ultrasound methodology for assessing a number of aspects of central and peripheral blood flow and cardiovascular function, specifically in rapid changes in intravascular circulating volume. This study

Subject wearing Braslet device.

uses the Braslet-M occlusion cuff system, which is a Russian-made operational countermeasure pre-calibrated and available on board for each ISS crewmember.

The Braslet study uses multiple modes of ultrasound imaging in combination with short-term application of Braslet-M occlusive cuffs and cardiopulmonary maneuvers to demonstrate and evaluate the degree of changes in the circulating volume on orbit. Measurements are performed without the Braslet-M, with Braslet-M applied, and immediately after releasing the occlusion device.



Remote guidance practice of the Braslet SDTO in the Protocol Development Laboratory at the Johnson Space Center.

In addition to the primary goal of methodology validation for cardiovascular evaluations, operationally relevant procedures will be developed to rule out a number of mission-impacting medical conditions. Space-adapted and non-invasive methodologies to study peripheral and central blood flow are a significant contribution of this investigation that can later be used to evaluate other countermeasures, as well as to diagnose or rule out arterial, venous, and cardiac pathology during flight. This investigation will provide pilot data regarding the effect of occlusion cuffs on the cardiovascular system of long-duration crewmembers and reveal whether it can be used as a means of acute or chronic volume manipulation for medical purposes. Future work would specifically examine the Braslet-M effects on cardiovascular system physiology, its safety, utility, and potentially new or expanded uses. The results of the current investigation will be used to optimize the preflight and inflight training modules for subsequent ISS crews.

In late 2007, 2 ISS crewmembers conducted the first inflight testing sessions for this study with additional inflight sessions occurring in 2008 for a total of 5 completed scanning sessions. More testing is scheduled for ISS Increment 18 and 19 crews. Preliminary results indicate that this relatively complex cardiovascular evaluation can be guided remotely using minimally trained operators. As compared to measurements taken without Braslet applied, the following changes have been reliably detected with Braslet applied: jugular (neck) vein cross-sectional area is reduced, femoral (leg) vein cross-sectional area is increased below the point of occlusion, and cardiac dimensions are reduced. Changes can also be detected in cardiac parameters using flow and tissue Doppler during respiratory maneuvers. More detailed analysis will be possible as the sample size increases.

Lightweight Trauma Module delivered to the ISS Program for Flight Development

The lightweight-trauma module is an integrated suite of physiological-monitoring therapeutic hardware and software. The lightweight-trauma module's software provides an infrastructure for patient-side and remote care with integrated data storage, autonomous care, and remote monitoring and control. The system is able to support ongoing closed-loop ventilation and intravenous-fluids administration research for the reduction of consumables, care-provider and crew training, and mission risk by reducing the requirements for constant patient-side attention by a crew medical officer.

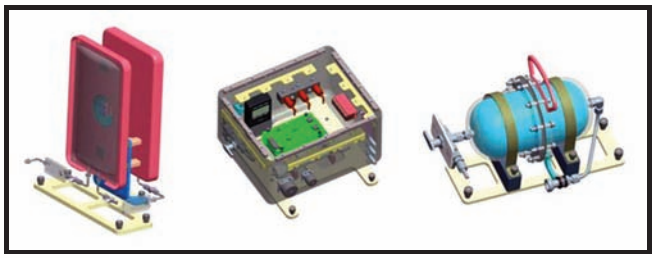
The components integral to the current lightweight-trauma-module prototype include a ventilator, 12-lead electrogram, pulse oximeter, noninvasive blood pressure, end-tidal carbon dioxide, temperature, invasive arterial pressure, Ethernet communications, closed-loop ventilation and intravenous fluids control, electronic medical record (data storage/export), and alarming and smart help.

The lightweight-trauma module transferred from technology design efforts in the HRP to spaceflight development efforts focused on putting the lightweight-trauma module on ISS. This hardware will significantly reduce the mass of the ISS Health Maintenance System and solve some of the obsolescence issues the system is facing after nearly 10 years on orbit. Making this hardware operational on ISS will ensure a solid spaceflight pedigree for the device when it is time to use it on exploration missions.

Latest version of the LTM being developed for use on ISS and future exploration missions.

Intravenous Fluid Generation (IVGEN)

Intravenous fluid to adequately treat an ill or injured crewmember during exploration missions is an important part of the crew health care system. Currently, NASA uses pre-filled IV bags that require significant mass and volume and have a limited shelf life. The IVGEN project is developing hardware that can produce medical grade IV fluids from on-board water sources. By doing so, NASA will not incur large mass and volume penalties associated with flying intravenous fluid and resupplying that fluid when it expires during exploration missions.



IVGEN components currently being fabricated for its ISS demonstration in 2010.

On February 22, 2008, the IVGEN project completed the preliminary design review. Following the approval of the conceptual design at the preliminary design review, the IVGEN project proceeded to test at the breadboard level and further refine the design. The critical design review was successfully completed in November 2008. This review panel granted approval for the IVGEN project to begin flight hardware fabrication in preparation for the flight demonstration in 2010.

Biosensors for EVA and Exercise Countermeasure Evaluation

In 2008 the team expanded the evaluation of the noninvasive sensors to analog space environments. Testing as part of the on-going bed rest studies was initiated this year. The sensor was also evaluated in simulated lunar gravity as part of the EVA Physiology, Systems & Performance Project's test protocols. The sensors were shown to detect increases in muscle oxygen extraction as work effort increased. Meanwhile, development of a miniaturized sensor was initiated with complimentary funding from the U.S. Army.

The sensor technology was developed at University of Massachusetts Medical School. A new company, Reflectance Medical Inc., has been established to commercialize the sensor technology for the care of critically ill patients in hospitals, emergency transport vehicles and near the battlefield.

Subject wearing the sensors.

Integrated Medical Model (IMM)

In its role supporting work on the integrated-medical model, Glenn Research Center augmented and applied its bone fracture module in several key ways. First, at the request of the program scientist of the HRP, Glenn Research Center analyzed the probability of a hip fracture associated with an unhindered fall to the side from a height of 1 meter for subjects who have participated in long-duration spaceflight. The analysis concluded that the loading was sufficient to cause a fracture even in the hip of an individual who had not suffered microgravity-induced bone loss. Glenn Research Center also augmented the bone module by providing an additional element quantifying the probability of wrist fractures given appropriate loading conditions and anatomical changes associated with spaceflight. The analysis determined that wrist fracture had a much higher probability than hip or lumbar spine, in part due to more frequent opportunities to endanger the wrist with heavier loading. Finally, Glenn Research Center completed an analysis requested by flight surgeons that studied the probability of inflight fracture associated with long-duration stays on ISS. Results indicated that the increased fracture probability during microgravity was negligible.

Glenn Research Center also completed work on an integrated-medical model module that predicts the likelihood of an astronaut requiring sleep medication based on circadian rhythm upset associated with shifting work schedules. An independent subject matter expert panel reviewed the methodology underlying the module, supporting the integrated medical model approach.

Life Science Data Archive

A laboratory technician at the Biospecimen Storage Facility at Ames Research Center shows samples archived from the Space Life Sciences-3 Mission.

The Life Sciences Data Archive project completed a physical inventory of all specimens stored in the Biospecimen Storage Facility at Ames Research Center. The inventory verified the availability and location of over 10,000 samples from flight and ground animal research, some dating from the Apollo era, others more recently added from the Foton-M2 mission (a 2005 collaboration with the European and Russian space agencies). The archive contains both frozen and unfrozen specimens, including animal tissue samples from bones, muscles, and organs. The inventory is used by life scientists both internal and external to NASA, including our International Partners, to further their research relevant to NASA's goals and missions. In return for using NASA's spaceflight tissue samples, researchers will provide their final reports and publications to be archived by Life Sciences Data Archive.

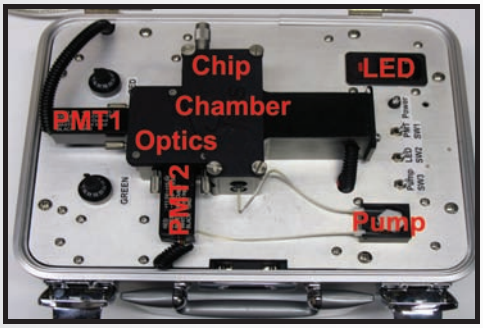
The Life Sciences Data Archive project also completed media migration (from inflight video tapes to digital video disc [DVD]) for an extensive flight tape collection from the Space Life Sciences-1 and Space Life Sciences-2 missions. Interested parties can request DVDs due to the historical value of the flight experiments and for education and public outreach.

Evaluation of Physiological Monitoring Devices for Exploration Missions

ExMC Element teams from the Johnson Space Center, Ames Research Center, and Glenn Research Center supported testing of physiological monitoring systems conducted at the National Center for Human Performance at the Texas Medical Center in Houston. The ExMC Element team assembled a suite of physical fitness routines and simulated lunar surface tasks (shoveling, picking up rocks, and climbing ladders), the National Center for Human Performance tested 2 sensor systems for ambulatory physiological monitoring—the Hidalgo Equivital and the Orbital Research/BioWatch systems. The Hidalgo system was evaluated by 8 female and 5 male subjects. The Orbital Research/BioWatch system was evaluated by 3 female and 4 male subjects. The tests will help hardware developers improve physiological monitoring systems for future EVAs and routine inflight medical monitoring. The National Center for Human Performance delivered to the ExMC Element a report of lessons learned regarding sensor placement, comfort, signal quality, and ways to make such systems sufficiently rugged to withstand the rigorous exploration environment.

A test subject performs a simulated lunar surface task at the National Center for Human Performance during physiological monitoring system tests.

Zero-G Demonstration of Portable Micro Flow Cytometer



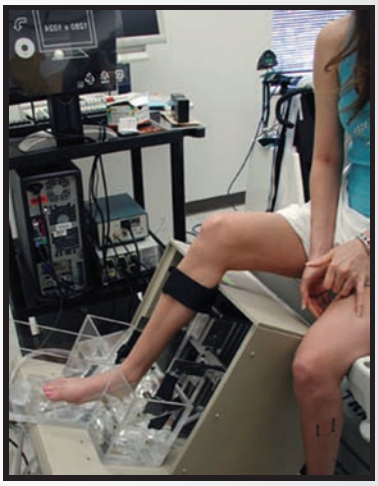
Portable, white-blood-cell counter.

Principal investigators from Cal Tech and NSBRI in collaboration with the ExMC Element have developed a portable, white-blood-cell counter with 2-part differential. This project addresses a key need cited by flight surgeons for treating astronauts at risk for radiation-induced illnesses and infection. Recently the device was successfully demonstrated in a zero-G test flight in collaboration with ExMC Element employees from the Wyle Integrated Science and Engineering Group.

The test system was developed jointly by scientists from Cal Tech, UCLA, and Iris Diagnostics. In addition to its intended use in space, the portable white-blood-cell counter is expected to find use in emergency rooms, ambulances, and eventually in the home market.

Bed Rest Demonstration of Noninvasive Bone Quality Assessment System

Principal investigators from Cal Tech continue to improve their novel noninvasive, ultrasound-based system to assess bone quality. In collaboration with the Johnson Space Center's Bone Laboratory, the system was evaluated on 29 subjects in the bed rest facility for 90 days, in comparison to the gold standard bone-density test measurement. Strong correlation was observed between heel assessments with the ultrasound system and bone-mineral density determined by bone density scans. Cal Tech's ultrasound system successfully detected bone loss during this microgravity analog study.



The ultrasound system was developed in collaboration with Luna Innovations, Inc. and is expected to have Earth applications in the diagnosis of osteoporosis.

Space Human Factors and Habitability (SHFH) Element

The major deliverables for the SHFH Element are validated models for predicting the effects of interface designs on human performance; methods for measuring human and human-system performance; design concepts for and evaluations of advanced crew interfaces and habitability systems; and requirements for spacecraft and space missions.

The SHFH Element consists of 3 main project areas:

- Advanced Environmental Health (AEH) Project
- Advanced Food Technology (AFT) Project
- Space Human Factors Engineering (SHFE) Project

The AEH Project focuses on understanding the risk of microbial contamination of the spacecraft and the development of lunar dust exposure standards. The AFT Project focuses on reducing the mass, volume and waste of the food system for exploration missions, while investigating processing methods to extend the shelf life of food items. An integral part of food system development ensures that nutritional value and palatability are maintained. The SHFE Project establishes human factors standards and guidelines for human-machine interactions to ensure optimal productivity of the crew.

Advanced Environmental Health (AEH) Project

How potentially toxic are lunar dusts? The AEH Project is well on its way to answering this important question and developing permissible exposure limits for episodic exposures lunar dust. The lunar dust health standard may aid NASA engineers in determining the hardware, countermeasures and procedures that will be taken to limit the presence of lunar dust in lunar Lander, habitat and lunar rover.

Lunar Dust

During the Apollo missions, NASA found that lunar dust was pervasive and it not only stuck tenaciously to astronaut's clothing and boots, it was abrasive to the suit material. The dust was irritating to the eyes and at times to the respiratory system. The particles are sharp, irregular shapes that formed by meteorite strikes over millions of years. These strikes melted the lunar dust into larger particles, and then broke them into jagged glass-like fragments, many in the respirable size range. Unlike dust on Earth, which is formed by wind and water erosion and is constantly smoothed by friction, lunar dust remains jagged unless it is once again melted. Unshielded ultraviolet rays and charged solar wind from the Sun give the surface of lunar dust particles a reactive surface. These surfaces have nothing to react with, so they remain active indefinitely, whereas on Earth (and in a habitable environment) particle surfaces become inactive through reactions with water vapor and oxygen.

AS17-145-22224 (12 December 1972) – Astronaut Eugene A. Cernan, Apollo 17 commander, is photographed inside the lunar module on the lunar surface following the second extravehicular activity (EVA-2) of his mission. Note lunar dust on his suit.

Lunar dust has properties that most toxicologists would consider suggestive of moderate toxicity. It consists of an appreciable fraction of ultrafine dust capable of penetrating deep into the lungs, and is likely to possess surfaces activated by radiation reaching the Moon's surface. Elemental iron is a major component of the respirable fraction of dust, and iron is known to increase dust toxicity when tested in cellular systems.

2008 Accomplishments

During 2008, the AEH Project made significant progress in characterizing lunar dust and developing methods for toxicity testing. Progress included understanding lunar dust toxicity in terms of dust morphology, chemistry, reactivity, cellular effects, and whole-animal effects. Together these findings are beginning to focus our understanding of lunar dust toxicity and point to quantitative results that will facilitate recommending an exposure standard in 2010.

Production and Properties of Lunar Dust

Our research team has investigated several methods to produce respirable-sized dust grains for the toxicological inhalation studies. Thus far, ball-mill grinding has produces desirable results. This method minimizes contamination from the grinding process and produces suitable-sized grains with partially-activated surfaces. Work is underway to optimize this grinding method.

Dissolution of dust, once it enters the pulmonary system, is an important mechanism for disposal of the dust. The team has noted key differences in the dissolution of minerals in aqueous media of varying pH. Dissolution studies will be extended to measurements in lung-surfactant-like fluids since lung surfactant is the first fluid the dust will encounter first in the body.

Lunar Dust Activation and Toxicity of Cells in Culture

The time duration of dust activation in a habitable environment is essential to our understanding of the relative toxicity of fresh (activated) lunar dust and aged lunar dust. How long must the dust be in the habitat before its reactive surfaces have been passivated? Studies employing different means of activation and different methods of quantifying the degree of activation are pointing to activation times in habitable air on the order of 1 to 2 hours. This suggests that exposure standards may be more stringent immediately following an EVA when fresh dust has entered the habitat.

Using markers for toxicity (inflammation) in cellular systems, our results have suggested that these markers are sensitive to increasing concentrations of dust simulant and that increased exposure duration of the cells to a given concentration of dust appear to result in a higher response from the toxicity markers. These studies will be expanded to include authentic lunar dust.

AS17-145-22157 (12 December 1972) - Scientist-astronaut Harrison Schmitt, Apollo 17 lunar module pilot, uses an adjustable sampling scoop to retrieve lunar samples during the second Apollo 17 extravehicular activity (EVA-2), at Station 5 at the Taurus-Littrow landing site.

Toxic Responses to Lunar Dust Exposure in Rodent Test Subjects

In cooperation with the National Institute for Occupational Safety and Health (NIOSH), intratracheal instillation toxicity studies of standard dusts and authentic lunar dust were conducted in rodent test subjects. Based on data available at this writing, it is suggestive that dusts produce a plausible dose-response curve for indices of toxicity. Additional studies include histopathology of lung tissue and pulmonary lymph nodes from exposed animals and differential cell counts on the cells in the lung-lavage fluid.

Surface Water and Air Biocharacterization (SWAB) Flight Experiment

Human presence in space, whether permanent or transient, will be accompanied by the presence of microorganisms. While most are harmless or even beneficial, several microorganisms pose a threat to crew health and spacecraft system performance. In addition to infectious disease, microorganisms can be responsible for toxin production, food spoilage, plant disease, volatile organic gases, biodegradation of spacecraft materials, and the fouling of environmental systems. Environmental analyses of the Mir and ISS have demonstrated an increase in microbial diversity and risk of contamination over the life of ISS. Thus, understanding the microbial ecology aboard the vehicle during flight is critical to determining and mitigating risk during long-duration missions, such as exploration missions to the Moon and Mars.

Thomas Reiter, European Space Agency astronaut and Flight Engineer-2, collects a surface sample near the Lamp Housing Assembly in the U.S. Laboratory Destiny for the Surface, Water, and Air Biocharacterization Flight Experiment. The photo was taken during Increment 13.

Historically, spacecraft analysis techniques have used culture-based methodology, which contain specific nutrients designed to grow certain types of microorganisms. Recently, the development of molecular biology techniques and instrumentation have allowed a far more comprehensive evaluation of the environment than previously possible with traditional culturing techniques. Samples for the SWAB flight experiment were collected from air and surfaces on ISS prior to the 8 vehicle dockings with ISS between Increments 13 and 18 using unique hardware flown specifically for this investigation. Water samples also will be taken in the future from the ISS potable water dispenser. Samples have been and will continue to be returned to Earth for processing, where a variety of techniques are used to analyze the samples including bacterial and fungal molecular identification, and quantitative techniques to identify and enumerate specific genes. Preflight samples and those returned from flight have been evaluated using denaturing gradient gel electrophoresis, a molecular technique that allows identification of the bacteria without the need for growth on media. The organisms identified using this method differed from those previously isolated from similar sampling locations using culture techniques. Several samples have also been analyzed using quantitative polymerase chain reaction to detect the presence of several viruses, including varicella-zoster virus. This organism is carried by many people and can “reactivate” under certain conditions causing the very painful disease shingles. The information collected during this experiment is critical to understanding the microbial flora on

long-duration missions. By using the data from the SWAB flight experiment and incorporating new molecular technology, a better understanding of microbial risk will be achieved, and NASA will better be able to mitigate the risk to crew health and vehicle integrity during the exploration missions to the Moon and Mars.

Advanced Food Technology (AFT) Project

The AFT Project is responsible for providing the crews with a food system that will enable safe, reliable, and productive human space exploration. The food system must be safe, nutritious, and acceptable to the crew, while efficiently balancing appropriate vehicle resources such as mass, volume, waste, and food preparation time for exploration missions. This food system will require the provision of a packaged food system with a shelf life of 3 to 5 years. Current Shuttle and ISS food system technologies cannot meet these requirements. The importance of the food system in a long-duration manned exploration mission should not be underestimated. The food system provides not only the nutrients needed for the survival of the astronauts, but also enhances the psychological well being of the crew by being a familiar element in an unfamiliar and hostile environment.

2008 Highlights

Comparative Packaging Study

Shelf life of foods can be reduced drastically upon interaction with moisture and oxygen. A good food packaging system functions to protect food items from exposure to these elements, by providing a flexible yet firm barrier against them. The current rehydratable and natural form packaging system for the ISS-food system consists of a primary package enclosed within a secondary overwrap. The primary package is a minimal barrier, transparent material (Combitherm®), which aids in processing and quality control; while the secondary overwrap is a high barrier, opaque material that ensures the product is protected and can meet the minimum shelf-life requirement of 18 months. While the overwrapped system consistently guarantees shelf life, it also generates more mass, waste, and labor than would a single material system.

Packaged foods provide the crew with safe and nutritious for long periods of time.

A translucent, high barrier material (Tolas®) has been identified that may provide the required 18-month shelf-life without the need for an overwrap, thereby reducing the current system to a single package. An 18-month comparative packaging study is being performed to evaluate the effectiveness of the Tolas® material against our current primary packaging material (Combitherm®) and a material similar to our current overwrap (Technipaq®). Two food products (dry oat cereal and peanuts) and 1 ingredient (cottonseed oil), which are extremely susceptible to the effects of oxygen and moisture, have been packaged in each material. The packaged products have been stored at varying relative humidity levels (25%, 50%, 75%), to simulate conditions that might be encountered on the Orion vehicle. Moisture intake and oxygen-induced spoilage of the products is being measured every 3 months by instrumental methods and sensory evaluation. As the study approaches 9 months, results have indicated that the Combitherm® material does not provide a sufficient barrier and would require an overwrap system,

while the Technipaq® and Tolas® materials each appear to maintain adequate barriers on their own. Successful performance of the Tolas® material might allow optimization of the current ISS packaging system by reducing it to a single package. The comparative packaging study will be completed in 2009.

Thermostabilized Shelf Life Study

We are investigating the long-term stability of thermostabilized food products, as they are currently being considered to support long-duration missions. Thermostabilized food products are processed with an aggressive heat treatment that ensures the safety and sterility of the products. This heat treatment, however, can also result in a loss of nutrients, flavor deterioration, or other quality changes in the foods. These changes are largely dependent on the composition of the food product, can be affected by storage conditions, and often intensify over time. Shelf life refers to the time it takes for a food product to become unsuitable, and was defined in this study in terms of the product's nutritive value and palatability. Foods for use in long-duration missions will require a shelf life that is between 3 and 5 years.

Rhubarb applesauce after being stored 36 months at 40 °F, 72 °F, and 95 °F. The color became much darker, the flavor decreased, and the nutritional value decreased as the temperature increased."

A 36-month accelerated shelf-life study was completed on a starch product (Homestyle Potato) and a fruit product (rhubarb applesauce) in 2008. In the starch product, folic acid and pantothenic acid significantly declined over time. In addition, the flavor decreased over time, primarily due to an acidic aftertaste, off aroma, and overall decrease in flavor. The vitamin C and folic acid of the fruit product significantly declined over time. In addition, the color darkened over time with the higher temperatures darkening more than the 40 °F sample due to oxidation. The remaining thermostabilized items, including egg and meat products (broccoli soufflé, vegetable omelet, and grilled pork chops) completed shelf-life testing in the fall of 2009. Preliminary results indicate thermostabilized processing is not appropriate for egg products, but may support meat products up to 87 months. A summary report estimating the shelf life of all 60 of NASA's thermostabilized food items will be prepared in 2009.

Effect of Processing and Subsequent Storage on Nutrition

Space crews rely upon the foodstuffs provided through NASA to meet their nutritional requirements. As missions extend to longer durations, the provisions have even more influence on the long-term physiology of space travelers. NASA adheres to strict requirements for the nutritional content of astronaut food during preparation. However, because vitamin degradation occurs with heat processing, oxidation, and light exposure, it is likely that the commercially sterile foods of the space program have reduced nutrient profiles at the time of consumption.

To evaluate the nutritional quality of current foodstuffs for prolonged space missions, a study to examine the micronutrient and mineral levels of space food after processing and long-storage times (up to 5 years) is underway. Currently 15 samples, either thermostabilized or irradiated to achieve sterility, have been chosen for the study. The samples include a wide range of fare: crawfish étouffée, beef enchiladas, and apricot cobbler, to name a few. The nutrient content of the pre-sterilized product was

estimated using Genesis® R&D software, and the post-sterilization nutrient content was determined analytically. The results show consistent loss in vitamin C levels (mean: 47% reduction) but varying sustainment of thiamine and vitamin A after processing (mean reductions: 38% and 17%, respectively). Additionally, folic-acid levels are higher than anticipated, driven either by a release of bound folate during the heat sterilization or poor estimations of the original folic acid content (mean: 168% increase). Replicate food samples will be analyzed again for nutrient content at 1 year and 3 years to understand storage impact. Sixty additional foods will be added to the study in 2009.

The Space Food Research Facility retort processes food with heat and pressure to sterilize it so it will stay safe for long periods; but heat and pressure also can destroy the nutrients.

Space Human Factors Engineering (SHFE) Project

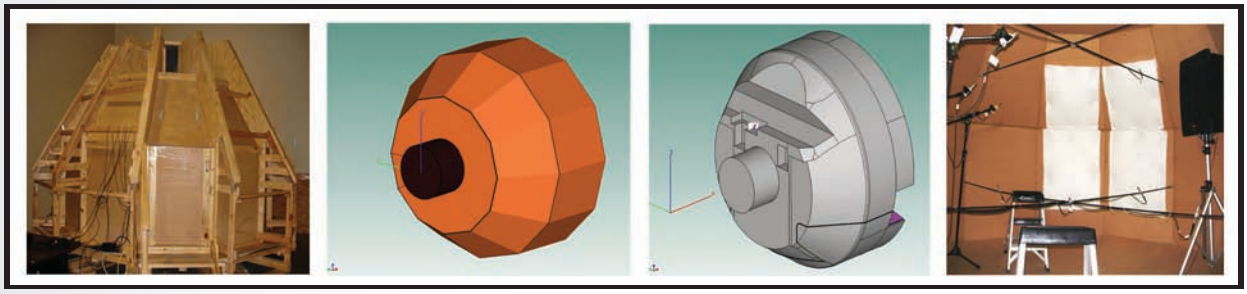
Design of NASA's next spacecraft is underway, and the SHFE Project is focused on questions the designers need answered. The new spacecraft will shake crewmembers during launch much more than previous spacecraft did, so we studied the effects of vibration plus acceleration in a centrifuge for the first time since the Apollo flights. We also compared different ways of making inputs to the spacecraft, and for displaying caution and warning information to the crewmembers. Spacecraft are very noisy because all the equipment is enclosed in a single structure, and everything needs fans for cooling. This makes it difficult for crewmembers to talk to each other and to the ground, and to sleep. To help designers know how much noise their equipment will cause, we have developed an acoustics model that predicts noise levels in the spacecraft before the equipment is built.

2008 Highlights

Acoustic Environment Modeling Accomplishments

A statistical energy analysis acoustic model of Orion's crew-module mockup was developed and validated by 10-microphone sound-pressure level measurements inside the mockup during FY08. A statistical energy analysis vehicle model based on the geometry from crew-module's inner mode line was also developed during 2008. The model has been used for snorkel fan and Environmental Control Life Support System's acoustic noise predictions.

The crew-module mockup has been prepared for a snorkel fan acoustic demonstration to help with requirements development in 2009. Sound absorbing material was attached to the interior of the mockup to control the acoustic reverberation inside the mockup. The amount of absorption was determined using the statistical energy analysis modeling and the resulting reverberation was verified using reverberation-time tests. Also, a noise simulation facility was developed for creating defined noise environments and a modified rhyme test was developed and used to evaluate the effect of mockup interior noise on speech interference and voice communications.



Orion acoustic mockup 1 | Acoustic Analysis model 1 | Orion CM 606-c acoustic model 1 | Orion snorkel fan demonstration 1

Fault Management Studies

A pair of operational concepts for real-time fault management on next generation crewed spacecraft were evaluated recently in NASA's Intelligent Spacecraft Interface Systems ascent simulator. One of our concepts, called Elsie, combines the operational advantages of a fully electronic (soft) suite of fault management interfaces (including an electronic procedure viewer), with the relatively modest software requirements of a stand-alone caution and warning system modeled after the current system on Shuttle. The other concept, called Besi, incorporates considerably more automation than Elsie, most notably a reasoning engine that diagnoses the proximal (root) cause of caution and warning system events. Eight-trained participants worked systems malfunctions during simulated Crew Exploration Vehicle's Orion ascents with Elsie and Besi. In parallel, participants were also tasked with noticing and responding to occasional changes in the color of an element on their primary flight display. Not surprisingly, participants worked the malfunctions more quickly and more accurately with Besi than with Elsie.

In 2008, extensive analyses were conducted of operators' oculomotor (eye movement) behavior during the initial phases of the fault management task for Elsie and Besi. These analyses revealed that most of the extra time required to complete root cause fault diagnoses and retrieve off-nominal checklists on the electronic procedure viewer with Elsie involved processing text on cluttered (text-rich) display formats. The findings suggest that designers of fault management operations concepts for dynamic phases of flight should pursue opportunities to reduce operators' needs for text processing wherever possible, particularly on cluttered text-rich displays. In addition, analyses of fixation patterns and transition probabilities between system summary displays, caution and warning fault messages, and electronic procedure viewer's menus revealed that operators consistently interleaved multiple sequential information acquisition episodes from all simultaneously visible sources of fault-management related information. This pattern strongly suggests that the fault management operational concept for Crew Exploration Vehicle should include the requirement that all critical fault-management-related information (e.g., fault messages, graphics-based system summary displays, and electronic procedure viewer menus) should be available for simultaneous viewing, preferably on one consolidated fault-management display.

Recording eye movements while subject works a malfunction

Cursor Control Design

The HRP's Information Presentation research project has completed several studies looking at cursor control design for the space environment. Past activities focused on development of a software test battery that can be used to evaluate and compare cursor control devices, as well as the usability of various devices in a space vehicle, such as Orion, which will go to the Moon and Mars. The Orion cursor control device must function well in high-gravity, vibration, and microgravity, and must be operable with pressurized space gloves. This makes the design of this device very challenging. Cursor-control device testing has been completed in a laboratory and in a pressurized glove box, using commercially available devices as well as some proprietary aircraft devices.

In 2008, the focus of testing moved to another critical topic—cursor movement. A free-flowing, continuous display cursor, like most computers have, may be difficult to use accurately in a high vibration environment. One might need, instead, a discrete type of cursor movement, where the cursor jumps from display object to display object—like tabbing in an electronic form. Another way to improve accuracy is to use a gravity well that captures the cursor and pulls it to the nearest target. A study was conducted to look at how cursor movement and type of device affect response time and accuracy. Participants were asked to use a trackball or a castle switch with different cursor movement types while completing a representative task. Participants completed the task with and without space gloves. Cursor movement was either continuous, discrete, or gravity well. The study confirmed that if accuracy is very important, a discrete mode or gravity well is the best choice, although these solutions are challenging to implement. If speed is more important, a trackball with a continuous cursor is the best choice.

The studies planned for 2009 will look at cursor control device performance in high vibration environments using vibration platforms to simulate the vehicle vibration that may be encountered during launch and reentry. Results from these studies are helping answer important design questions and providing design guidelines and requirements for future space missions.

Pressurized Glovebox study | Castle Switch Prototype | Kensington Trackball | Study Task Display

Behavioral Health and Performance (BHP) Element

The BHP Element conducts and supports research to address 3 human system health risks: Risk of Performance Errors due Sleep Loss, Fatigue, Circadian Desynchronization, and Work Overload (Sleep); Risk of Performance Errors Due to Poor Team Cohesion and Performance, Inadequate Selection/Team Composition, Inadequate Training, and Poor Psychosocial Adaptation (Team); and Risk of Behavioral and Psychiatric Conditions (B-Med). Lunar and Mars missions will require long duration stays in remote, isolated, and unique environments, with extended periods of heavy workload. Day and night cycles will differ from standard Earth time; teams composed of only a few individuals will experience prolonged confinement as well as times of monotony. BHP Element deliverables will yield technologies and methods to aid the behavioral health and performance of astronaut crews, during and following these exploration missions.

The BHP Element conducts research inflight and in space-analog environments to develop and validate tools and technologies for the detection, prevention, and treatment of behavioral health and performance decrements. The Sleep-risk area currently focuses on countermeasure development, including lighting, medications, sleep hygiene, and work-rest schedules; the BHP Element's risk area examines team performance and cohesion gaps and develops tools and technologies to unobtrusively monitor interpersonal interactions, and indicators of cohesion and performance, while B-Med research aims to develop monitoring and self-assessment tools for early detection and treatment using unobtrusive and objective measures of affect, fatigue, and stress reactions to living and working in spaceflight.

The BHP Element's strategy for addressing its risk reduction research gaps is systematically derived and operationally driven. The end result is to optimize the adaptation of the individual and crew to the space environment and maintain motivation, cohesion, communication, morale, and productivity.

2008 Highlights

Journals

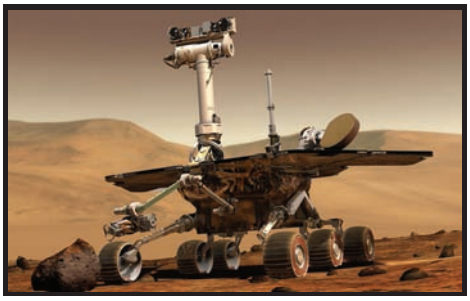
The Journals experiment recently achieved a major milestone as data collection for 10 subjects was completed in 2008. The objective of this study is to obtain behavioral and human factors data from a systematic analysis of astronaut journals maintained during ISS increments. Ten ISS crewmembers over 10 increments have maintained personal journals, which are now under review by the principal investigator for content analysis. Findings from this study will help inform gaps across our Sleep, Team and B-Med Risks, particularly related to behavioral health countermeasure effectiveness over long-duration missions. Interestingly, while serving as a means to collect data that will help inform Exploration

Ten Astronauts on the ISS have participated in the Journals experiment. Findings from this study will help NASA understand the current risks and countermeasures for behavioral health, in preparation for future long duration missions to the moon and Mars.

missions, the study also benefited the current crews; Bill MacArthur, Commander of ISS Increment 12, expressed praise for the study, stating that maintaining a journal during his mission helped him to manage the frustrating and positive aspects of his long-duration stay in space.

Phoenix Scout Lander

A principal investigator and a multi-institutional team of investigators supported the ground crews of the Phoenix Scout Lander (Mars Robotic Mission) with countermeasures to help mitigate the effects of sleep loss, fatigue and circadian desynchronization. The Phoenix Scout Lander launched in August of 2007 and landed at the polar region of Mars in May 2008 to study the history of water and habitability potential of the Martian surface. The ground crews supporting this mission opted to work and live on a Mars day, or "Sol", and in doing so, added approximately 39 minutes to each work day. This schedule had the potential to result in circadian misalignment, sleep disruption and performance decrements throughout the 3-month mission. Adding to the challenge, some local members of the ground crew lived with their families who maintained their normal Earth day.



Artist rendition of the Phoenix Scout Lander on the Mars surface.

The crews from previous robotic Mars missions—including the Mars Pathfinder, Spirit and Opportunity—reported adverse effects on their sleep and performance when adopting a Mars Sol. As a result, the Phoenix Scout Lander principal investigator requested our help to support his team. The principal investigator provided blue-light boxes and practical, evidence-based recommendations for sleep and for facilitating synchronization to the Mars sol; concurrently, the investigators collected data over the course of the mission (including melatonin markers via urine samples, performance data via the psychomotor vigilance task and an automated neuropsychological assessments metrics performance battery, and subjective ratings of sleep) to evaluate the effects of the schedule on the circadian system, and to assess the acceptability, feasibility and effectiveness of the countermeasures. The findings from this study will inform Flight Medical Operations and Mission Operations for exploration mission planners, crews supporting Mars robotic missions, and current Shuttle and ISS missions, where shifts in the timing of the sleep-wake schedule and sleep loss can be physiological challenges. In addition, lessons learned from this study will allow for more specific investigations with future robotic ground crews.

The Virtual Space Station (with NSBRI)

Psychosocial problems can threaten the success and safety of long-duration space missions. With funding from the NSBRI, principal investigators are developing a suite of interactive media programs to help long-duration flyers prevent, detect, assess, and manage their own psychosocial problems. The system, dubbed the Virtual Space Station, currently includes content to help with depression and the management of interpersonal conflict. Additionally, a stress management module is under development by a scientist at the University of California at Los Angeles. Future modules could be added—even after mission launch—to address other aspects of behavioral health. The system supports crew autonomy because it can be used independently or in conjunction with the flight medicine team. All data is secured via encryption and password protection, and the researchers are working closely with Medical Operations and the Astronaut Office.

The depression component of the Virtual Space Station enables crewmembers to identify signs and symptoms of depression and receive problem-solving treatment, a behavior therapy for depression that has strong empirical support. A principal investigator guides users through the program on pre-recorded video as if they were in a live problem-solving treatment session. It enables crewmembers to receive therapy for depression, even with long communication delays between the space and ground crews. A randomized clinical trial of the problem-solving treatment program is currently underway.

Screenshot of the Virtual Space Station

This NSBRI-funded task addresses gaps in the Risk of Behavioral and Psychiatric Conditions. Specifically, this deliverable will help crews detect, assess, and ameliorate decrements in behavioral health.

Psychomotor Vigilance Task Self-Test on ISS (completed in analogs, upgrade to a personal computer version)

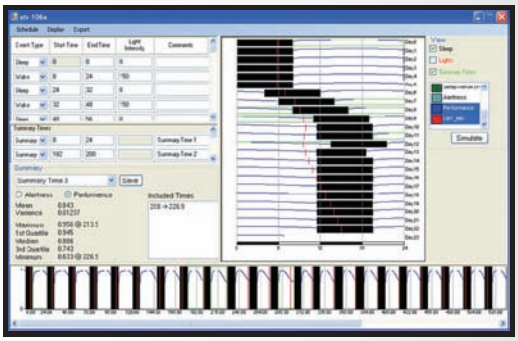
The Psychomotor Vigilance Task Self Test was selected as an ISS flight experiment starting in September of 2009. The Psychomotor Vigilance Task Self Test, which NASA has named the Reaction Self Test on the ISS station support computers, is a highly sensitive, brief, objective measure of core cognitive processes involving stability of attention, vigilance errors, and reaction time deficits. Using speed of the nervous system together with errors of omission and commission, the test provides objective feedback on performance relative to fatigue from sleep loss and related fatigue factors. The Psychomotor Vigilance Task Self Test supports autonomous operations by providing information to the crew surgeon and astronaut, so that appropriate countermeasures, if necessary, can be implemented.

The principal investigator and his research team developed and validated the Psychomotor Vigilance Task Self Test with specific consideration for the unique demands faced by astronauts. As an example, the Psychomotor Vigilance Task Self Test now requires minimal crew time (test duration is 3 minutes). The measure has been validated for its sensitivity to fatigue, and ground-based performance norms were developed on astronaut during training. In addition to using astronaut performance on the test to develop an optimized performance algorithm, the principal investigator solicited feedback from astronauts as he developed the user interface for the Psychomotor Vigilance Task Self Test, to ensure usability and acceptability. Crewmembers involved in Increment 21–22 have recently consented to participate in the Reaction Self Test study on ISS. Psychomotor Vigilance Task Self Test performance data on ISS will help complete the normative database for this highly skilled and specialized population.

The Psychomotor Vigilance Task Self Test study on ISS will not only yield a brief practical validated measure of cognitive performance inflight, it also will aid in addressing a high priority gap for exploration missions—namely, accurately characterizing and quantifying the human health risk of performance errors due to sleep loss, circadian desynchronization, fatigue and work overload.

Circadian Performance Simulation Software

Anecdotal and empirical evidence has revealed that during space missions, circadian rhythms and sleep are disrupted, both for those working in space and for the mission crews supporting them from Earth. The BHP Element is currently evaluating aspects of the spaceflight environment and conditions of the missions (Shuttle, ISS, and anticipated Lunar and Mars) that may lead to disturbed sleep. Individual vulnerabilities to sleep loss also serve as an important consideration in this assessment, as both ground and spaceflight studies have revealed large variability in the effects of sleep loss on performance and health.



Screenshot of the Circadian Performance Simulation Software.

The principal investigator and the associate team leader of the Human Factors and Performance team of the NSBRI, has developed and validated a physiologically-based mathematical model of sleep, circadian rhythms, and performance and alertness that includes the key interactions between the processes of circadian rhythms, sleep-wake homeostasis and sleep inertia. Current work on the model is focusing on individual predictions, instead of group average predictions, for the response to circadian misalignment (e.g., after jet lag, “slam shifts”, or rapid changes in schedule due to operational constraints) and extended work hours, and will incorporate actigraphy data as an objective measure of sleep-wake activity as well as the response to different wavelengths of light.

The principal investigator’s deliverable will help current operations as well as mission planners for exploration to develop schedules and countermeasures designed for optimizing individual performance, alertness and quality sleep relative to operational requirements. The Circadian Performance Simulation Software (currently available at **http://sleep.med.harvard.edu/research/faculty-research/tools/CPSS**) helps inform research gaps in the Sleep Risk area, particularly those related to individual vulnerabilities to sleep loss, as well as gaps related to countermeasures and optimal work-rest schedules for shifting and sleep loss.

Education and Outreach

Human Research Program Education and Outreach (HRPEO) Project is committed to using NASA's space research and exploration to educate the nation on science, technology, engineering and mathematics. Project activities and materials target educational communities, the general public, policymakers, and the media using formal and informal venues. The HRPEO Project has made notable strides in their K-12 programs and outreach efforts. Their primary grade programs include the *21st Century Explorer, Fit Explorer and Sports and Exploration*, while their secondary programs include *Math and Science @ Work* and *Exploring Space through Math*. All program details can be found at **http://humanresearch.jsc.nasa.gov/education.asp**.

2008 Highlights

Fit Explorer International Challenge (FEIC) Informal World-Wide International Space Station Partner Event

Physical inactivity and unhealthy diet are 2 of the most significant health risks on Earth that lead to the diseases such as high blood pressure, cardiovascular disease, type-2 diabetes, as well as others. The U.S. Department of Health and Human Services recently released guidelines for all Americans. The prevalence of overweight on a worldwide level has steadily increased over the past two decades in both adults and children. This concern over an ever-increasing sedentary population of children and adolescents is worldwide with studies from the U.S., Canada, France, Germany, Japan, Spain, Russia, Great Britain, and others. The Fit Explorer International Challenge (FEIC) will be a world wide challenge which offers another means by which countries and youth groups can provide children background on good nutrition and fitness as well as strive to become and stay more active. The FEIC seeks to inspire and educate young people world-wide that good fitness and nutrition are life-long endeavors. The Challenge uses the current space exploration programs as the backdrop for "Getting and Staying Fit in both Body and Mind". The FEIC objectives are to 1) compile set of ISS Partner educational materials that assist the end-user with understanding what world-wide efforts are on-going to promote healthy life-styles, 2) inspire and engage young people about health and fitness while experiencing life on ISS through a set of down-link communications, 3) coordinate and implement "in-country" Fit Explorer challenges, and 4) hold a ISS Partner Fit Explorer Challenge and final event.

The FEIC effort will be further organized in 2009 and the challenge teams will begin in 2010 with the culminating event to occur in April 2011. April 7 of each year is celebrated as World Health Day. Underway are plans for the development of an inspirational 8-minute video by the participating countries, identification of "in-country" events leading up to the Fitness Challenge and recruitment of additional countries to participate in the Challenge. In 2011 the winning Challenge teams will be recognized by their country and will have an opportunity to talk with the current crew of the International Space Station. The FEIC is

lead by HRPEO's Fit Explorer Project staff and during the concept and planning phase has successfully recruited support from Canada/CSA, France/CNES, Germany/DLR, and Japan/JAXA. Meetings have been held with JSC Office of Education, President's Council on Physical Fitness and Sports (PCPFS), local area YMCA, and the Astronaut Office to gain their support for the effort. The concept document and briefing packages have been completed along with the first in a series of international telecoms to coordinate ideas, set near-term events in each participating country and to begin work on the FEIC 8-minute video.

Fit Explorer Train Like an Astronaut Videos

During 2008, the Fit Explorer project completed the video productions for the first 5 of 10 Train Like an Astronaut activities. The intent of the one minute video segments is to help the challenge team participants perform the activities properly and better understand why these activities are important to space explorers to ensure they remain strong and healthy during all phases of their space flight missions. The videos were shot at the local YMCA facility. During each a NASA Trainer guides the students through the activities. In collaboration with the YMCA in League City, Texas, summer camp students were chosen to help demonstrate appropriate techniques in conducting the following missions: Base Station Walk-Back, Do a Spacewalk, Jump for the Moon, Crew Strength Training, and Mission: Control! An Astronaut Strength Conditioning and Rehabilitation Specialist will take viewers through each mission explaining the techniques being demonstrated. These videos will be added to the NASA Fit Explorer website in 2009 and development will start on the second set of 5 activities.

Also during 2008 the Fit Explorer project was presented to more than 700 K-12 students at the 3rd Space Exploration Conference & Exhibit at the American Institute of Aeronautics and Astronautics conference in Denver, Colorado February 27–28, 2008 . The American Institute of Aeronautics and Astronautics is a premier venue for networking with business, government, and technology leaders from across the country.

AfterSchool Review Accepts NASA HRP E & O Manuscript

A manuscript was accepted in April 2008 as part of the spring edition for the AfterSchool Review. The topic for the issue will be, "Science in AfterSchool". The publication will focus on a variety of articles that incorporates science learning in after-school programs, and was distributed in May 2008. National AfterSchool Association professional members represent the broad diversity of the after-school field, including youth-serving organizations, school-based and community-based, private, and Department of Defense programs. The AfterSchool Review is distributed to more than 9,000 members and 36-state affiliate organizations.

Human Research Program Displays & Recognition Received with a NASA Gallery Award

The Human Research Program Education and Outreach team supports their projects with overall imagery, branding, and creative material design. All graphic work is made compliant with NASA style guide standards and submitted for approval to the NASA Communications Materials Review. In July 2008, an approved display banner designed by an HRPEO Project's team member received the Gallery Award from the NASA Office of Communications and Planning. The banner, entitled Space Exploration AP was selected as one of the best designs of 2008. The design was chosen using the criterion of creativity, compliance with style guide standards, visual effectiveness, and practicality. The focus of the banner is Math and Science @ Work and highlights advanced placement subjects (calculus, physics, chemistry, biology, and statistics) and their relationship with human space exploration. The Space Exploration AP banner is featured on the NASA Communications Review Gallery.

NSBRI

The NSBRI supports a robust education and outreach program encompassing a variety of activities from kindergarten to independent investigator, including curriculum and teacher professional development, undergraduate and graduate education, and postdoctoral fellowships.

NSBRI Summer Internship Program

National Space Biomedical Research Institute's Summer Internship Program received 101 applications in 2008 with 15 students selected for 10 to 15 week placements with space life sciences projects at JSC. In January 2008, NSBRI began discussions with representatives of Glenn Research Center and Ames Research Center about the possibility of expanding the Internship Program to those Centers. NSBRI interns will be placed at both the Johnson Space Center and Glenn Research Center in summer 2009 with plans to expand to Ames Research Center in 2010. In 2008, the Internship Program added a Professional Development Workshop to its activities. The workshop included grant-writing, resume-writing and interview skill sessions, as well as suggestions on how to stay involved with space-related research. The Internship Program actively recruits applicants through university career fairs and online postings through university career centers.

NSBRI Graduate Education Program

In 2008, the NSBRI Graduate Education Program in Space Life Sciences completed its second year. Eleven students are enrolled in the integrated project jointly awarded to Texas A&M University and the Massachusetts Institute of Technology (MIT), through the Harvard-MIT Division of Health Sciences and Technology. The graduate program is developing modules to strengthen current graduate curricula at the two institutions, enabling students to experience advanced courses in biomedical science and engineering as these fields relate to the space program. Once fully developed, the educational modules will be applicable to accredited doctoral program across the nation. Each summer, the students attend

the Bioastronautics Graduate Education Summer Institute, which includes 1 week of seminars and workshops led by various NSBRI and NASA researchers and by faculty at Baylor College of Medicine followed by a 6 to 8-week research internship at JSC.

NSBRI Podcasts and Podcasts Plus Lessons Communicate Science and Technology Achievements

Twelve NSBRI podcasts produced by EarthSky Communications debuted in fall 2008, establishing a highly successful method of informing the public about research advances. Six team leaders and investigators were interviewed to create the 90-second and 8-minute podcasts.

The short pieces aired on EarthSky's 1,700+ broadcast outlets in their global network, which includes Voice of America and World Radio Network. The short and long podcasts are also accessible on the EarthSky Website. NSBRI's Education Program supplemented the effort with "Podcasts Plus Lessons". Posted on the NSBRI and BioEd Online websites, this resource provides teachers with the podcasts, plus related lessons and activities to download for classroom use.

Space Life Sciences Summer Institute at the Johnson Space Center

The Space Life Sciences Summer Institute, sponsored by HRP, runs through June and July every summer. Each intern is assigned a JSC mentor within the biomedical laboratories and participates in ongoing research. In addition to conducting research within our laboratories, we offer lectures and tours twice a week to expose the students to various aspects of human spaceflight.

SLSSI lecture series.

The Institute's educational goals are to provide:

- Exposure to cross-disciplinary physiological aspects of human spaceflight
- Interaction with students from multiple backgrounds and universities
- Opportunities that offer a broader perspective of how their summer research fits in to the overall NASA Vision for Exploration.

SLSSI participants touring the Neutral Buoyancy Laboratory

This was the 4th year for the Institute and included 24 lectures from guest speakers, ranging from astronauts, scientists, engineers, flight surgeons, and flight directors. Additionally, tours were provided of Mission Control Center, Neutral Buoyancy Laboratory, Shuttle and Space Station training mock-ups as well as a demonstration of the Advance Crew Escape Spacesuit. We believe these opportunities give the student a broader perspective how their work fits in to the overall NASA Vision for Exploration.

Summer intern participation in the 2008 Space Life Sciences Summer institute included 58 interns, both undergraduates and graduates, from 36 colleges and universities in 19 states, with an average participation of 28 students per lecture. For more information visit our website at: **http://hacd.jsc.nasa.gov/resources/slssi.cfm**.

Future Plans for the Human Research Program

As the HRP begins its fourth year of operation, a major milestone will be completion of the Standing Review Panels planned for the fall of 2009. The panels will consist of discipline experts, engineers, and project management specialists who will review all scientific and technological aspects of HRP work. These merit reviews will determine the quality, relevance, and value of the work to ensure the HRP is meeting its objectives to investigate and mitigate the highest risks to human health and performance for human space exploration.

Constellation will receive HRP products to further vehicle and system designs. Deliverables for the Orion vehicle preliminary design review will include the acoustics model, occupant protection requirements, and cockpit display and caution and warning requirements. In addition, the HRP will provide inputs to the suit parameter design requirements for the EVA Suit Configuration-1 preliminary design review.

Experiment operations will continue in ground analogs and on ISS. The HRP and its NSBRI partner are participating in the Institute of Biomedical Problems of the Russian Academy of Sciences 105-day chamber study. This experiment, which begins in March 2009, is a simulation of a 6-person ISS crew. The 3 NASA NSBRI behavioral health and performance studies to be conducted are: photic countermeasure to improve alertness, performance, and mood; objective monitoring tools for neurobehavioral functioning, and crew interactions and autonomy during long duration isolation and confinement. In the Antarctic-Concordia environment, the European Space Agency and HRP investigators will collaborate to determine the validity of the Antarctic long-duration winter-over as a spaceflight associated immune dysregulation ground analog. Radiation research capabilities will be enhanced with implementation of the 20-inch beam width at the NASA Space Radiation Laboratory at the DoE's Brookhaven National Laboratory. For the ISS, the advanced resistive exercise device launched in November on STS-126. In 2009, HRP researchers will use this next generation device to further study the effectiveness of high-load resistive exercise to prevent musculoskeletal deconditioning. These HRP tasks will continue to provide data to further understand and mitigate the impact of the space environment on the human system.

The HRP will announce selections for 2008 NASA research announcements, "Research and Technology Development to Support Crew Health and Performance in Space Exploration Missions" in April and "NASA Specialized Centers of Research in support of Space Radiation" in May. The HRP is on schedule to release 2009 NASA research announcements in early March for space radiation and late July for all other HRP exploration biomedical research. These NASA solicitations will be in concert with the research announcement releases from the NSBRI.

During the annual Investigators' Workshop in February, participants will share information regarding the current status of research and technology developments for the HRP's

human health and performance risks. The workshop has served and continues to be a beneficial forum for disseminating knowledge and fostering collaboration within the HRP and research communities.

The HRP will complete significant revisions and synchronization of all documents. Revisions to the HRP's Commitment Agreement and Program Plan will be approved through the Exploration Systems Mission Directorate and Agency management, as needed. The Program Requirements Document and Integrated Research Plan will be updated to reflect current HRP risk, gap, and task content. Changes to these program-level documents will result in updates to the element-level documents. This document synchronization effort will further refine HRP management structure and strengthen implementation, which is essential for providing quality deliverables on time.

The HRP will continue to define the challenges of human space exploration and mitigate associated risks. The HRP made significant strides in 2008 to fortify program organization and execution, conduct research and technology developments, and provide products to the Constellation Program and to the Office of the Chief Health and Medical Officer. In 2009, the HRP will continue to deliver key information and products for preventing and mitigating human health and performance risks to ensure crew health and performance and exploration mission success.

How to contact the Human Research Program:

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Back: Astronaut conducts lunar surface EVAs, in the vicinity of the Lunar Electric Rover.

2008 Human Research Program Annual Report

National Aeronautics and Space Administration

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