

Human Research Program Utilization Plan for the International Space Station



2012 Update



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August 2012

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Human Research Program Utilization Plan for the International Space Station – 2012 Update

NASA's Human Research Program (HRP) goal is to provide human health and performance countermeasures, knowledge, technologies, and tools to enable safe, reliable, and productive human space exploration. To meet that goal, NASA analyzed the value and necessity of the International Space Station (ISS) to quantify and address the human health and performance risks for crews during exploration missions. Based on a set of exploration risks, the HRP defined a research and technology plan to address the risks. This plan is documented in the Human Research Roadmap (<http://humanresearchroadmap.nasa.gov>) and sets the following goals to be completed by the end of the ISS in 2020:

- to perform the research needed to identify and quantify risks to human health and performance
- to identify potential countermeasures
- to flight validate those countermeasures

1. Introduction

NASA's Human Research Program has a comprehensive Integrated Research Plan (IRP) that includes both flight and ground experiments and facilities. NASA sharpened the human research focus on exploration missions to a Near Earth Asteroid (NEA) and Mars. HRP annually publishes analyses of the risks cataloged in the Human Research Roadmap and determines the next steps in research and technology to quantify the risks and, wherever possible, reduce these risks to acceptable levels.

The ISS, as an orbiting, microgravity laboratory, provides an invaluable platform to secure knowledge, test countermeasures, and evaluate technologies important for the development and validation of risk mitigation techniques for exploration missions. The research plan for various risks is laid out as a progression of activities that are designed to address critical questions that must be answered to quantify the risk or develop mitigation strategies for the risk.

The activities on ISS are essential for two reasons. First, because there is no effective ground-based analog to conduct the work on Earth, or secondly, the research activity needs the complete operational environment of space flight to validate the countermeasure (CM) or technology. The ISS is necessary to mitigate 23 of the 32 human health risks anticipated on exploration missions. Only those human system risks that require use of the ISS to support mitigation tasks are described in this document. The list of risks to be addressed on the ISS is given in Table 1 below.

Human Research Program Risks Addressed on ISS
1. Risk of unacceptable health and mission outcomes due to limitations of in-flight medical capabilities
2. Risk factor of inadequate nutrition
3. Risk of performance decrement and crew illness due to an inadequate food system
4. Risk of adverse behavioral conditions and psychiatric disorders
5. Risk of radiation carcinogenesis from space radiation
6. Risk of compromised EVA performance and crew health due to inadequate EVA suit systems
7. Risk of early onset osteoporosis due to spaceflight
8. Risk of orthostatic intolerance during re-exposure to gravity
9. Risk of impaired performance due to reduced muscle mass, strength and endurance
10. Risk of reduced physical performance capabilities due to reduced aerobic capacity

11. Risk of clinically relevant unpredicted effects of medication
12. Risk of performance decrements due to inadequate cooperation, coordination, communication and psychosocial adaptation within a team
13. Risk of cardiac rhythm problems
14. Risk of intervertebral disc damage
15. Risk of crew adverse health event due to altered immune response
16. Risk of impaired control of spacecraft, associated systems and immediate vehicle egress due to vestibular/sensorimotor alterations associated with space flight
17. Risk of performance errors due to fatigue resulting from sleep loss, circadian desynchronization, extended wakefulness, and work overload
18. Risk of bone fracture
19. Risk of renal stone formation
20. Risk of spaceflight-induced intracranial hypertension/vision alterations
21. Risk of adverse health effects due to alterations in host-microorganism interactions
22. Risk of decompression sickness
23. Risk of an incompatible vehicle/habitat design

Table 1. Twenty-three HRP Risks That Require ISS

Research is inherently non-linear. As NASA gains knowledge, understanding of the required approach changes. This document represents the best plan available at this snapshot in time and is based on annual assessments of progress since November of 2007. It would be impractical to assume a linear approach with respect to future research plans. This plan will continue to be revised and updated based on consideration of new evidence gained, available resources, exploration needs, and other driving schedule constraints.

NASA also fully intends to continue making efficient use of ISS resources through cooperative research with ISS Partners. NASA actively works with the European Space Agency (ESA), Russian Space Agency (RSA), Canadian Space Agency (CSA), and the Japan Aerospace Exploration Agency (JAXA) to ensure that research is coordinated to reduce overlap and take advantage of efficient research combinations.

2. Summary of Progress Since 2007

NASA has implemented the ISS flight studies identified in the 2007 plan and made significant progress understanding and mitigating the health risks associated with human space flight. Significantly, NASA has made progress in the following areas:

- 1) understanding how to manage space-induced bone and muscle loss by using new exercise protocols and pharmaceutical and nutritional countermeasures;
- 2) behavioral and performance risks associated with sleep disruptions and monitoring of crewmember alertness;
- 3) demonstrating exploration medical capability including in-flight intravenous (IV) fluids production;
- 4) management of crewmember orthostatic intolerance;
- 5) added new ISS biomedical capabilities including the second-generation ultrasound for medical imaging, the urine monitoring system, and the jointly developed ESA/NASA muscle atrophy research and exercise system, and Portable Pulmonary Function System (PPFS); and
- 6) identified a significant health risk, Risk of Spaceflight-Induced Intracranial Hypertension/Vision Alterations (Short Title: VIIP), that has already been incorporated into future ISS flight plans.

Since the 2007 Human Research Plan, HRP has completed or started the following ISS research and technology activities:

Completed

- ISS Urine Monitoring System (UMS)
- ISS Ultrasound 2 to provide high-resolution biomedical images
- Evaluation of Commercial Compression Garments to Prevent Post-Spaceflight Orthostatic Intolerance
- Sleep-Wake Actigraphy and Light Exposure During Spaceflight
- Behavioral Issues Associated with Long Duration Space Expeditions: Review and Analysis of Astronaut Journals
- Spinal Elongation and Its Effects on Seated Height in a Microgravity Environment
- Surface, Water, and Air Biocharacterization - A Comprehensive Characterization of Microorganisms and Allergens in Spacecraft Environment
- Cardiovascular and Cerebrovascular Control on Return from ISS (NASA managed and implemented in agreement with CSA)
- Intravenous Fluid Generation for Exploration Missions

In Progress

- Cardiac Atrophy and Diastolic Dysfunction During and After Long Duration Spaceflight: Functional Consequences for Orthostatic Intolerance, Exercise Capacity, and Risk of Cardiac Arrhythmias
- Maximal Oxygen Uptake During Long Duration ISS Missions
- Bisphosphonates as a Countermeasure to Space Flight Induced Bone Loss
- Validation of Procedures for Monitoring Crewmember Immune Function
- Nutritional Status Assessment
- Physiological Factors Contributing to Changes in Post-Flight Functional Performance
- An Integrated Resistance and Aerobic Training Study for the Validation of an Exercise Countermeasures Regimen Aboard the ISS
- Biomechanical Analysis of Treadmill Exercise on the ISS
- Dietary Intake Can Predict and Protect Against Changes in Bone Metabolism During Spaceflight and Recovery
- Psychomotor Vigilance Test (PVT) on ISS (re-initiated after crew size was increased from 2-3 to 6)

In 2008, the NASA Chief Medical Officer established the Human System Risk Board (HSRB) to review and assess all Human system risks. The HSRB determined that several risks identified in 2007 did not require research to understand nor mitigate. The following operational risks were removed from the HRP:

Risk of operational impact of prolonged daily required exercise
Risk of unnecessary operational limitations due to inaccurate assessment of cardiovascular performance
Risk of urinary tract dysfunction
Risk of adverse health effects due to exposure to hypoxic environments
Risk of adverse health effects due to prolonged exposure to elevated carbon dioxide levels

Table 2. HRP Risks Removed in 2008

In addition to those risks removed from the research program, two new risks were added:

- Risk of Adverse Health Effects Due to Alterations in Host-Microorganism Interactions
- Risk of Decompression Sickness

Currently, HRP is conducting 14-16 studies per increment, with an additional 5-6 experiments being prepared for flight. Results are made publically available as soon as practical, while maintaining priority of publication for the investigators if practical. Results are published in scientific and technical journals, NASA technical publications, and the HRP Evidence Reports. HRP Evidence Reports are available at <http://humanresearchroadmap.nasa.gov/Evidence/>

NASA is continually updating both its strategic and tactical plans to optimize ISS experiment throughput and maximize crew participation in biomedical flight experiments. The HRP strategic plans associated with each risk area are contained in the Integrated Research Plan (IRP). The IRP is available via the Human Research Roadmap (<http://humanresearchroadmap.nasa.gov/>) and is updated on a yearly basis. The tactical ISS plans list the current and planned human research experiments that will be undertaken in each ISS increment and is updated continually throughout the year. This ISS Fly-off Plan is available at the ISS Medical Projects website (http://www.nasa.gov/exploration/humanresearch/elements/research_info_element-issmp.html).

The following sections describe the risks, progress since 2007, and updates to planned activities that require use of the ISS. After each risk title, the responsible HRP Element is identified. The Elements of HRP are Space Radiation (SR), Human Health Countermeasures (HHC), Exploration Medical Capability (ExMC), Behavioral Health and Performance (BHP), Space Human Factors and Habitability (SHFH), and ISS Medical Projects (ISSMP).

Appendix A traces the IRP, Rev C ISS experiments to HRP risks, Appendix B lists select products and publications from work on ISS since 2007, and Appendix C lists acronyms and abbreviations used in this document.

3. Human Health and Performance Risks

3.1 Risk of Unacceptable Health and Mission Outcomes Due to Limitations of In-Flight Medical Capabilities (ExMC)

Mission architecture limits the amount of equipment, consumables, and procedures that will be available to treat medical problems and there is a risk that, given the resource limitations, some conditions may go untreated. Mission allocation and technology development must be performed to ensure that the limited mass, volume, power, and crew training time are used efficiently to provide the broadest possible treatment capability.

Role of the ISS in quantifying the level of risk or acquiring additional information to confirm or eliminate risk.



Figure 1. IVGEN Technology Demonstration

To provide the broadest possible treatment capability, NASA will develop and test technologies using ISS to make the best possible use of the limited mass, volume, power, and crew training. Analyzing bodily fluids (urine, blood, saliva) in-flight will reduce launch/return mass/volume and provide the data near real-time in lieu of postflight results. A system to perform real-time analyses is necessary to meet these requirements. ISS will be important to establish that blood and urine analytical devices can be operated routinely in the microgravity environment.

Onboard advanced medical life support hardware will be required to treat the crewmembers on a regular and emergency basis. Technologies which are smaller, lighter, reliable, and more user-friendly will be required to fit within the limited space of the spacecraft. This includes an automated fluid resuscitation capability requiring less training than the conventional method and an open architecture ultrasound device giving a robust and extensible framework and platform for novel ultrasound uses and technologies. The ISS is used to develop and demonstrate these capabilities. In addition, the ISS is used to demonstrate systems for providing medical suction capability, dental care technology, medical and crew health management, and injectable medication packaging, preparation and delivery.

The ISS is used to develop a system that generates in situ intravenous fluids, which includes the production of an acceptable IV solution that meets United States Pharmacopeia (USP) requirements, on orbit verification using available microgravity-compatible technology and techniques, collection of sufficient engineering data to enable the scaling of the system to meet mission needs, and end-to-end demonstration of system level performance.

Currently on the ISS, the crewmember's source of contingency oxygen if needed is the onboard oxygen tanks. The contingency system would provide 100% oxygen to the crewmember continuously and could exceed the spacecraft oxygen limit within minutes. For future spacecraft, a contingency system which concentrates the oxygen within the cabin environment and provides the required concentration of oxygen to the crewmember will be necessary. The ISS will be used to develop an oxygen concentration capability which is small, light weight, and requires low power usage.

When ISS medical kits are returned to Earth, fewer medical consumables remain in the medical kits than is expected based on reported use by the astronauts. This raises the possibility that exploration missions might be undersupplied and risk being unable to treat an ill or injured crewmember. The ISS is used to identify current practices and develop controls, processes, and technical solutions to accurately track the inventory of medical consumables.



Figure 2. Diagnostic Ultrasound Guide

Progress in addressing the risk

Technology providing the ability to generate water for injection on-demand was demonstrated by the IntraVenous Fluid GENeration for Exploration Missions (IVGEN) project, the next generation Ultrasound capability was delivered to ISS and the HRP developed and delivered a diagnostic guide to assist with remote ultrasound imaging. Based on new destinations and a better understanding of the medical conditions, plans were updated to include the development and ISS demonstration of multiple medical devices, including an in flight laboratory analysis

device that will interface with an end-to-end Exploration Medical System, which will also be demonstrated on ISS before 2020.

Planned research to support	12	13	14	15	16	17	18	19	20
Risk of Inability to Adequately Recognize or Treat an Ill or Injured Crewmember									

3.2 Risk Factor of Inadequate Nutrition (HHC)

Adequate nutrition is a key factor in all physiological functions and spaceflight has been shown to alter many of these physiological functions in humans. Countermeasures for individual systems may alter the nutritional status with a possibility that inadequate nutrition will compromise crew health, including endurance, muscle mass and strength, immune function, bone mass and strength, cardiovascular performance, gastrointestinal function, endocrine function, and ocular, psychological and physical health, and ability to mitigate oxidative damage.

In general, nutritional risks increase with duration of exposure to a closed (or semi-closed) food system. Understanding nutrient requirements in micro- or partial gravity environments and the effect of countermeasures on nutrient requirements is critical to ensure crew health and safety and mission success. Provision of these nutrients in safe amounts (neither high nor low) depends on provision of appropriate, palatable, foods with the stability of nutrients for the duration of the mission, and actual intake of the nutrients, and knowledge that countermeasures are not altering requirements.

It is critical that crew members be adequately nourished before and during missions. Critical research areas within this risk include validation of the correct nutritional needs; assessment of the stability of nutrients during long duration flight; correct packaging and preservation techniques; effects of countermeasures on nutrition; and use of nutrients as countermeasures.

Role of the ISS in quantifying the level of risk or acquiring additional information to confirm or eliminate to risk.



Figure 3. Russian cosmonaut Oleg Kotov, Expedition 23 commander; and NASA astronaut Tracy Caldwell Dyson, flight engineer, are pictured near fresh fruit and vegetables floating freely in the Unity node of the ISS.

The ISS is used to improve the nutritional content of the food when consumed, identify the variety, acceptability, and ease of use for long-duration missions, validate correct nutritional needs, and quantify the stability of nutrients during long-duration flight. The ISS is required to ensure that the data represents space normal and for validation of potential countermeasures to inadequate nutrition. Flight validation of nutritional requirements will be complete in 2013, and updates to the nutrition standard will be made in 2018.

Progress in addressing the risk.

The Nutritional Status Assessment is providing a better understanding of the impact of nutrition on many key risks. HRP gained insight into the role of adequate nutrition, omega 3 fatty acids, vitamin D and folate in maintenance of bone and muscle, immune function, and potential predisposition for visual impairment. In addition, HRP's understanding of sodium intake and calcium balance in flight helped engineers understand and address malfunctions in the ISS Waste Collection System. Nutritional stability studies showed that the nutritional value of space flight food deteriorated at the same rate as on the ground, making the overall shelf life the greatest threat to the food system. Ongoing and planned studies will further clarify the impact of nutrition on other risks, as well as identify new nutritional countermeasures and extend the shelf life of the food system.

Planned research to support	12	13	14	15	16	17	18	19	20
Risk Factor of Inadequate Nutrition									

3.3 Risk of Performance Decrement and Crew Illness Due to an Inadequate Food System (SHFH)

If the food system does not adequately provide for food safety, nutrition, and acceptability, then crew health and performance and the overall mission may be adversely affected. Furthermore, if the food system uses more than its allocated mission resources, then total required mission resources may exceed capabilities, the mission may not be deemed feasible, or allocation of resources to other systems may be unduly constrained.

Role of the ISS in quantifying the level of risk or acquiring additional information to confirm or eliminate risk.



Figure 4. Food cans and packets floating freely on board ISS during Expedition 7. Preserving food for long duration exploration missions is important to the safety and health of the crew.

The ISS will be used to develop an acceptable food system by providing evidence upon which to base requirements. Researchers will determine if certain taste perceptions (salty, sweet, sour, bitter, umami) differ significantly in microgravity compared to perception on Earth, determine if spice intensity differs significantly when perceived in microgravity as compared to Earth, and recommend recipe modifications and/or condiment additions to improve the acceptability of the food system in microgravity. The data will be used to quantitatively confirm or rebut the commonly held notion that foods taste different in space and provide direction on how to improve acceptability of menu items in space.

The ISS is used to identify methods to enhance the eating experience on orbit. Researchers investigate how special meals and eating occasions as well as “cooking” on orbit can impact mood, stress, and behavior, identify trigger foods and determine the relative impact on mood of these foods, determine the effect of communal dining as compared to solo dining on mood state, determine the role of food preparation on mood and stress, and recommend dining behaviors and practices that positively affect the mood, stress, and behavior of crew on extended missions. The ISS is used to provide a quantitative assessment of the impact of food and dining on crew mood, stress, and behavior.

Progress in addressing the risk.



Figure 5. Stability experiment.

Exploration food systems require low mass, high quality, and long shelf life. Packaging failures, excess material, or oxygen trapped within the package can be detrimental to this system. Based on work by a Small Business Innovative Research project, HRP developed a Bulk Overwrap Bag (BOB) to reduce the need for double wrapping individual food items. The BOB is currently used in all ISS food packaging. The completion of the Nutrient Stability study referenced above showed that the nutritional value of space food is not compromised by space flight, thus future research on extending the shelf life of food, does not require the use of ISS.

New investigations planned for ISS will assess the impact of microgravity on taste, smell and mood.

Planned research to support	12	13	14	15	16	17	18	19	20
Risk of Performance Decrement and Crew Illness Due to an Inadequate Food System									

3.4 Risk of Adverse Behavioral Conditions and Psychiatric Disorders (BHP)

Behavioral issues are inevitable among groups of people, no matter how well selected and trained. Spaceflight demands can heighten these issues. The extended duration and the isolated, extreme and confined environments of future missions present the possibility that adverse behavioral conditions or mental disorders could develop should adverse behavioral conditions go undetected and unmitigated.

Scientific studies demonstrate that if left unmitigated, personal reactions such as those listed below, can erode individual motivation, morale and performance.

- Worry/anxiety over conditions of mission or on Earth that distracts from mission focus
- Anger/resentment toward others that affects cooperation during mission
- Insufficient training (Pre, In or Post-Flight)
- Depression/loneliness due to isolation from friends and family
- Unhappiness over role or treatment by others that leads to social isolation during mission

Acute or chronic conditions during spaceflight may also exacerbate the risk of developing a psychiatric disorder from these adverse behavioral conditions.

Role of the ISS in quantifying the level of risk or acquiring additional information to confirm or eliminate risk.

The ISS is used to emulate the transit environment to Mars to further characterize the risk of behavioral conditions and psychiatric disorders that can develop during long-duration space travel so that validated and reliable tools that predict, detect, and assess this risk can be identified and/or developed, and the appropriate countermeasures can be developed.

Progress in addressing the risk.

The final report of the study “Behavioral Issues Associated with Long-Duration Space Expeditions: Review and Analysis of Astronaut Journals” which began in 2003, was completed in June 2010. The objective of the study was to identify relevant behavioral factors and obtain data to inform decisions about priorities of various behavioral issues, in order to prepare for future spaceflight missions. The report is based on what astronauts wrote about their experiences onboard the ISS for durations ranging from four to six months. This study provided the first quantitative data pertaining to the behavioral issues associated with long-duration spaceflight operations. A total of twenty-four issues were identified and rank-ordered.

The study found the crew wrote most about their work, followed by outside communications, adjustment to the conditions of spaceflight, crew interactions, recreation and leisure, equipment, events, organization and management, sleep, and food, in that order. Also, the study showed a decline in morale during the third quarter of each mission. The entries and analyses provide a comprehensive description of ISS operations from the crew perspective.



Figure 6. Crewmembers participating in Journals use laptops aboard the ISS to make entries of their thoughts for the day. The primary focus of the Journals investigation is to help the crew cope with isolation during long duration exploration.

Planned research to support	12	13	14	15	16	17	18	19	20
Risk of Adverse Behavioral Conditions and Psychiatric Disorders									

3.5 Risk of Radiation Carcinogenesis from Space Radiation (SR)



Figure 7. mBAND method used to detect aberrations within a chromosome pair.

Space radiation exposure increases cancer morbidity and mortality risk in astronauts. This risk may be influenced by other space flight factors including microgravity and environmental contaminants. Current space radiation risk estimates are based on human epidemiology data for X-ray and gamma-ray exposure scaled to the types and flux-rates in space using radiation quality factors and dose-rate modification factors, and assuming linearity of response. There are large uncertainties in this approach and experimental models imply additional detriment due to the severity of the phenotypes of cancers formed for the heavy ion component of the galactic cosmic rays compared to cancers produced by terrestrial radiation. A Mars mission may not be feasible (within acceptable limits) unless uncertainties in cancer projection models are reduced allowing shielding and biological countermeasure approaches to be evaluated and improved or unless mission durations are constrained.

Role of the ISS in quantifying the level of risk or acquiring additional information to confirm or eliminate risk.

The ISS data collected during nominal operations (i.e. not research/experimental activities) will be used to update recommendations on Human System Standards and Permissible Exposure Limits (PELs), provide scientific basis and recommendations on radiation protection requirements, update the Risk Assessment Model, baseline enhanced computational design tools for vehicle design assessment, and develop necessary countermeasures. Each ISS crewmember’s medical history is followed and these data are used to update risk models.

Progress in addressing the risk.

Radiation personnel develop and maintain an integrated tool set that collects the current best practices, databases, and state-of-the-art methodologies to evaluate and optimize space radiation protection for human systems such as spacecraft, spacesuits, rovers, and habitats. The On-Line Tool for the Assessment of Radiation in Space (OLTARIS) radiation design tool website was significantly enhanced in FY2010 to include updated light ion and neutron transport, multi-layer transport in user-specified materials, the calculation of back-scattered neutrons, and voxel-based human geometry models to more accurately calculate effective dose.

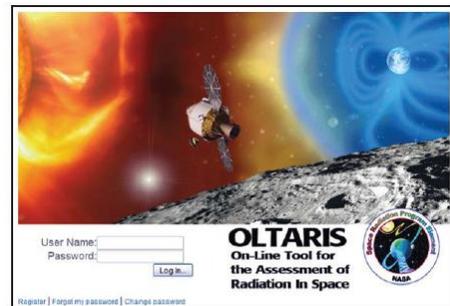


Figure 8. During FY10, several enhancements were made to the on-line OLTARIS tool to establish baselines for both Shuttle and Station radiation levels.

The Relativistic Ion Track Structure code (RITracks) developed by SR as part of the NASA Space Radiation Risk Assessment project calculates ionization and oxidative damage from space radiation in biological materials through Monte-Carlo simulations. RITracks includes models of human chromosomes for the entire genome, allowing the user to score the position of DNA damage in whole cells. These features are important for biological effects modeling to characterize and mitigate space radiation health risks.

(ongoing data collection during nominal operations)

Planned medical data collection to support	12	13	14	15	16	17	18	19	20
Risk of Radiation Carcinogenesis from Space Radiation									

3.6 Risk of Compromised EVA Performance and Crew Health Due to Inadequate EVA Suit Systems (HHC)



Figure 9. Attired in her Extravehicular Mobility Unit (EMU) spacesuit, NASA astronaut Tracy Caldwell Dyson, Expedition 24 flight engineer, prepares to exit the Quest airlock of the ISS.

Improperly designed extravehicular activity (EVA) suits can result in the inability of the crew to perform as expected, and can cause mechanical and decompression injury. Suit developers must fully understand the impact of the suit design on crew performance and health to ensure properly designed mobility, pressures, nutrition, life support, etc.

Performance of space flight EVA consists of placing a human in a micro-environment which must provide all the life support, nutrition, hydration, waste, and consumables management functions of an actual space vehicle, while allowing crewmembers to perform as closely as possible to a 1-g shirt-sleeved environment.

In the past, not all crewmembers were capable of performing EVA, as it was not a requirement in the context of their role during Shuttle and ISS missions. However, during the exploration program, all crewmembers will need to perform at a high level of competence in the suit. Therefore, it is critical to understand the relationships among suit parameters, subject characteristics, and health and performance.

Role of the ISS in quantifying the level of risk or acquiring additional information to confirm or eliminate risk.

The information from ISS-based EVAs will be used to identify suit-induced trauma and will be entered into a searchable database to track suit injury. In addition, the ISS data will be used to determine mission metabolic profiles and to quantify consumables during operations. Data from each ISS EVA will be used to optimize suit designs and determine metabolic profiles.

Progress in addressing the risk.

New exploration planning information identifies a need for extensive EVAs. In order to reduce the risk of Decompression Sickness from multiple or long EVAs, exploration planning groups are proposing to use an atmosphere different than that used on ISS. To address specific concerns with this approach, the risk of Decompression Sickness was separated from the risk due to the suit system and all research plans related to DCS were moved to the new risk. The HRP delivered a searchable database to track suit injuries, both in flight and during training. The database is used to identify trends and areas of concern for new suit development.

EVA metabolic data was used to develop a bioadvisory algorithm technology demonstrator, which is implemented into suited human performance tests conducted in support of new suit technology development projects. The intent of the demonstrator was to put into practice a metabolic rate calculation methodology using sensor driven data to ensure the validity of the calculations and to characterize the sensitivity and sensor requirements associated with these methods. Preliminary data indicates that the algorithm performs as intended, but further tests will be necessary and will be incorporated as additional objectives into future suit testing.

The functional specifications document was provided to the EVA Systems Project Office (ESPO) Technology Development Office in February 2010. The document provided specific detail regarding the metabolic calculations performed by the algorithm and a list of the necessary sensors.

(ongoing data collection during nominal operations)

Planned research to support	12	13	14	15	16	17	18	19	20
Risk of Compromised EVA Performance and Crew Health Due to Inadequate EVA Suit Systems									

3.7 Risk of Early Onset Osteoporosis Due to Spaceflight (HHC)

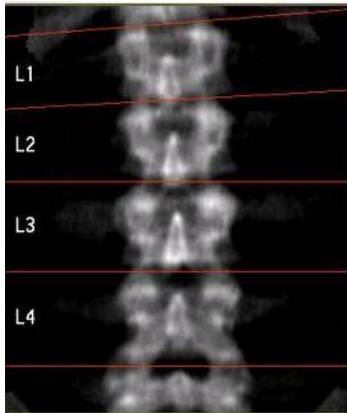


Figure 10. Dual Energy X-ray Absorptiometry (DEXA) scan of a human spine.

Osteoporosis is a skeletal syndrome that is characterized by low bone mass and severe structural deterioration. This condition can be due to aging or extrinsic factors such as Secondary Osteoporosis. Spaceflight-induced bone loss is classified as the latter and is not contingent upon age.

Bone mineral loss occurs in microgravity due to unloading of the skeletal system, with average loss rates of approximately 1% per month. It is unclear whether this bone mineral density loss will stabilize at a lower level, or continue to diminish. It is unknown if fractional gravity, present on the moon and Mars, would mitigate the loss. Likewise, the impact of multiple long-duration missions or of cumulative time in space is not yet established. Space exposure could be a risk factor for Secondary Osteoporosis after return to Earth and could put crewmembers at greater risk of osteoporosis-related fractures at an earlier age than expected for a terrestrial peer group. Greater understanding of the mechanisms of bone atrophy in microgravity, and for recovery after return, is necessary to frame this risk, as well as to understand how current and future osteoporosis treatments may be employed. This risk deals specifically with the likelihood of developing post-mission osteoporosis.

Role of the ISS in quantifying the level of risk or acquiring additional information to confirm or eliminate risk.

ISS is required to gather the space normal data needed to define long term recovery of bone mineral density. The ISS will be used to validate effective nutritional, pharmaceutical and exercise countermeasures to mitigate physiological deconditioning and protect against bone loss during spaceflight.

Progress in addressing the risk.

In 2010, a treadmill harness Station Development Test Objective (SDTO), sponsored by the Exercise Countermeasures Project, collected on-orbit comfort and load data in a side-by-side comparison of the current treadmill harness and a prototype harness designed at Glenn Research Center for improved comfort and loading. SDTO operations began during Increment 20/21 and continued through Increment 25. After testing was complete, the positive results and favorable feedback from the crew prompted NASA to provide a Glenn Harness for every crewmember who requested one as a “crew preference item.” In addition, a new study is in progress to look at treadmill kinematics. This study, Biomechanical Analysis of Treadmill Locomotion on the ISS, began in 2011 and will provide information on joint loading during treadmill exercise.

The HRP completed the “treatment” portion of the Bisphosphonate experiment in late 2011. The purpose of the study was to determine whether a bisphosphonate – a medication for osteoporosis – when combined with a crewmember’s routine in-flight exercise program, would protect against the loss of bone mineral documented on previous ISS flights. A review of the data revealed that the “treatment” subjects showed more stable maintenance of bone mineral density, but the data was compromised by the introduction of a new Advanced Resistive Exercise Device (ARED) midway through the experiment. In order to understand the independent contributions of exercise and pharmaceuticals to the structure and strength of the hip bone, a set of control subjects who exercise on ARED without bisphosphonates was added to the study.

HRP has also added two ISS investigations to assess nutritional countermeasures to changes in bone metabolism and assess the changes in bone micro-architecture and strength.

Planned research to support	12	13	14	15	16	17	18	19	20
Risk of Early Onset Osteoporosis Due To Spaceflight									

3.8 Risk of Orthostatic Intolerance During Re-exposure to Gravity (HHC)

Postflight orthostatic intolerance, the inability to maintain blood pressure while in an upright position, is an established, space-related medical problem. The CV system adapts to microgravity environment during space flight raising the possibility that crewmembers will suffer from post-flight orthostatic intolerance upon re-exposure to gravity. Orthostatic intolerance has been shown to progress to presyncope (inability to maintain standing blood pressure) in up to 80% of returning crew members tested with a post-flight tilt test. Currently available countermeasures are not effective in all crewmembers; in particular, women are more susceptible than are men.

Role of the ISS in quantifying the level of risk or acquiring additional information to confirm or eliminate risk.



Figure 11. Catherine (Cady) Coleman, Expedition 26 flight engineer, participates in the ambulatory monitoring part of the Integrated Cardiovascular (ICV) assessment research experiment in the Kibo laboratory of the ISS.

To better understand orthostatic intolerance, the ISS will be used to determine the magnitude and importance of cardiac atrophy associated with long duration space flight, and to relate this atrophy to measures of physical activity and cardiac work in-flight. Researchers will identify changes in ventricular conduction, depolarization, and repolarization during and after long duration spaceflight, and relate these to changes in cardiac mass and morphology. The ISS will be used to clearly define the clinical expression of cardiac atrophy during long duration spaceflight.

A number of countermeasures have been successfully identified and are under study for eliminating or minimizing the risk of orthostatic intolerance upon landing (fluid loading, compression garments, post-flight compression garments, etc.). The currently performed countermeasure for orthostatic intolerance, fluid loading, has been shown to improve a Cardiac stress index, but does not completely restore plasma volume. The ISS will be used to improve this countermeasure.

Progress in addressing the risk.

The study titled “Evaluation of Commercial Compression Garments to Prevent Post-Spaceflight Orthostatic Intolerance” began operations in 2010 with Shuttle crewmembers on missions to/from ISS. The purpose of this pre- and post-flight study was to investigate a method to protect returning space crews from orthostatic intolerance.

Preliminary evidence from this study suggests the use of compression garments can significantly improve orthostatic tolerance, provide superior fit and comfort for astronauts, and the garments are easier to put on than the current anti-G suit.

The “Test of Midodrine as a Countermeasure against Postflight Orthostatic Hypotension: SMO-006” investigation was terminated prior to completing all subjects due to a concern with known interactions with other pharmaceuticals commonly used for space motion sickness. Due to this limitation, the Deputy Chief Medical officer recommended HRP focus on mechanical countermeasures to orthostatic intolerance.

Planned research to support	12	13	14	15	16	17	18	19	20
Risk of Orthostatic Intolerance During Re-Exposure to Gravity									

3.9 Risk of Impaired Performance Due to Reduced Muscle Mass, Strength and Endurance (HHC)

There is a growing body of research evidence which suggests that skeletal muscles, particularly postural muscles of the lower limb, undergo atrophy and structural and metabolic alterations during space flight. However, the relationships between inflight exercise, muscle changes, and performance levels are not well understood. Efforts should be made to try to understand the current status of inflight and post flight exercise performance capability and what goals/target areas for protection are needed for the in-flight exercise program.

Role of the ISS in quantifying the level of risk or acquiring additional information to confirm or eliminate risk.



Figure 12. Ron Garan, Expedition 27 flight engineer, equipped with a bungee harness, exercises on the Combined Operational Load Bearing External Resistance Treadmill (COLBERT) in the Tranquility node of the ISS.

ISS will be required to evaluate and validate optimized exercise countermeasures and hardware (e.g., resistance exercise device, treadmill, cycle ergometer). Optimized countermeasures are those that need minimal exercise to free crewmember time for other tasks required for mission success, need minimal volume and hardware to maintain muscle mass, strength and endurance. The ISS will be used to validate the functional task tests that measure physiological decrements in crewmembers.

The ISS will be used to evaluate an integrated set of functional and physiological tests on returning crew members and use these tests to determine how postflight changes in sensorimotor, CV and muscle physiology impact postflight functional performance. Computational tools will be generated that will be useful in quantification of the physiological cost of exploration tasks, including quantifying joint kinematics during treadmill locomotion on the ISS, to compare the data to treadmill locomotion on Earth, and develop a computer model that will assess locomotion speed and external loading condition influenced upon joint torque.

Progress in addressing the risk.

The Muscle Atrophy Research Exercise System (MARES), a joint project between HRP and the ESA, launched on Shuttle mission STS-131 in April 2010 and was delivered to the ISS. ESA supplied the main testing apparatus and NASA supplied the rack and power interfaces.

MARES will be used to carry out research on musculoskeletal, biomechanical, neuromuscular and neurological physiology, to study the effect of microgravity on the human being, and to evaluate the effect of the countermeasures to the space environment induced physiological effects. It can also be used to evaluate the performance of exercise tests protocols.

Two new studies began in 2011. The Treadmill Kinematics investigation will also address the muscle risk and a new study “Integrated Resistance and Aerobic Training Study” will develop and test new interval protocols designed to maintain bone and muscle, while reducing the time required for exercise. Once the exercise prescription is optimized, it will be used to validate new exploration exercise devices designed to provide similar loads to those on ISS, but within a much smaller resource foot print.

Planned research to support	12	13	14	15	16	17	18	19	20
Risk of Impaired Performance Due to Reduced Muscle Mass, Strength and Endurance									

3.10 Risk of Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity (HHC)



Figure 13. Expedition 26 flight engineer Catherine (Cady) Coleman, performs VO2max portable Pulmonary Function System (PFS) software calibrations and instrument check while using the Cycle Ergometer with Vibration Isolation System (CEVIS) in the Destiny laboratory of the ISS.

Astronauts' physical performance during a mission, including activity in microgravity and fractional gravity, is critical to mission success. In addition to reduced skeletal muscle strength and endurance, reduced aerobic capacity may put mission success at risk. Sustained sub-maximal activities (even walking on a planetary surface) could become difficult to perform given large enough decrements in aerobic capacity.

Setting minimum fitness standards and measuring whether crew can maintain these standards will document the effectiveness of maintenance regimens.

Role of the ISS in quantifying the level of risk or acquiring additional information to confirm or eliminate risk.

The ISS will be used to measure aerobic capacity (VO2max) and cardiac output during and after long term space flight. In addition, the ISS will be used to optimize and subsequently to validate effective exercise prescriptions to mitigate physiological deconditioning during spaceflight to include aerobic capabilities as it relates to functional capacity and exercise volume, regimens, and equipment.

Progress in addressing the risk.

In FY 2012, the HHC Element will complete the final in-flight session for the VO2Max experiment designed to quantify the risk of reduced physical performance capabilities due to reduced aerobic capacity. This investigation validated the ability to directly measure VO2Max in flight and quantified the uncertainty in predictions using sub-maximal VO2 measurements. The Integrated Resistive and Aerobic Training Study will help ensure an exercise prescription that also maintains aerobic capacity.

Planned research to support	12	13	14	15	16	17	18	19	20
Risk of Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity									

3.11 Risk of Clinically Relevant Unpredicted Effects of Medication (HHC)



Figure 14. Kit containing all the items the crew will need for taking blood samples.

Because the human body undergoes a variety of physiological changes during spaceflight, there is a risk that terrestrial medications may not perform as expected when used during spaceflight. It could be that the spaceflight environment may require completely new therapeutic agents or prescribing tactics. Alterations in physiology due to spaceflight could result in unexpected drug action on the body (pharmacodynamics) or in unusual drug absorption, distribution, metabolism or excretion (pharmacokinetics). The spaceflight environment may also have direct effects on stored drugs themselves, leading to premature inactivation or degradation of drugs.

Role of the ISS in quantifying the level of risk or acquiring additional information to confirm or eliminate risk.

The ISS will be used to perform pharmacokinetic, pharmacodynamics and medication storage studies in a spaceflight environment. There are no existing ground analogs that adequately reproduce the microgravity and radiation effects associated with spaceflight, as far as multi-system pharmacological measures are concerned.

Progress in addressing the risk.

In November of 2008, the final “Stability of Pharmaceuticals and Nutrients in Space” study kit was returned on STS-126 after a 28-month stay on the ISS, having been launched on STS-121 in 2006. The pharmaceuticals payload for the Stability study included four identical pharmaceutical payload kits containing thirty-one medications in different dosage forms such as injectable liquids, pills and ointments. Environmental monitoring of the kit indicated that mean temperature and humidity were comparable on the ground and in space. However, cumulative radiation levels were significantly higher in space and increased as a function of time.



Figure 15. The Stability flight investigation evaluated pharmaceutical samples. The kits contained 31 medications in different dosage forms.

The results from the study indicated that a number of medications did not meet one or more USP stability criteria after spaceflight compared to their respective ground controls. A small number of pharmaceuticals were stable beyond their expiration dates, however, the number was greater for the ground control than the flight medications. This indicates the shelf life of pharmaceuticals in space may be compromised. Factors affecting the stability of pharmaceuticals may include vibration, cumulative radiation dose, and repackaging of dosage forms from their original commercial dispensers.

Planned research to support	12	13	14	15	16	17	18	19	20
Risk of Clinically Relevant Unpredicted Effects of Medication									

3.12 Risk of Performance Decrements Due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team (BHP)



Figure 16. STS-120 Doug Wheelock, Scott Parazynski, and Paolo Nespoli in Discovery's middeck.

Risk of performance errors due to poor team cohesion and performance, inadequate selection/team composition, inadequate training, and poor psychosocial adaptation is yet undetermined. Although behavioral health research has been well documented and identifies strong relationships among factors within the general population, the vast majority of this research is conducted using terrestrial samples. Little to no quantitative data is available that specifically addresses issues that relate to an astronaut population in a space environment.

By quantitatively identifying factors that are salient to defining behavioral health and well-being in the astronaut population, this study aims to provide direction to future operational research studies which are necessary to reduce risk as well as inform current operations.

Role of the ISS in quantifying the level of risk or acquiring additional information to confirm or eliminate risk.

The ISS will be used for flight validation of methods and technologies that monitor individual and crew for issues related to poor team cohesion and performance, inadequate selection/team composition, inadequate training, and poor psychosocial adaptation. These include facial recognition monitoring technology, voice acoustic technology, communications technology, and conflict management technology. In addition, the ISS crews will be used to collect data and gather evidence on the effects of increased autonomy on group cohesion and performance, determine the most effective methods for mitigating stress and low morale and investigate countermeasures to optimize performance (exercise, food, privacy, entertainment, etc).

Progress in addressing the risk.

Several new studies were selected for ISS to address this risk, focusing on the impact of increased crew autonomy. A pilot study "Assessing the Impact of Communication Delay on Performance: An Examination of Autonomous Operations Utilizing the ISS" has completed definition and is planned to begin in 2014. Several other studies are utilizing ground analogs prior to entering the definition phase for ISS.

Planned research to support	12	13	14	15	16	17	18	19	20
Risk of Performance Decrements Due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team									

3.13 Risk of Cardiac Rhythm Problems (HHC)



Figure 17. Leroy Chiao and Yuri Shargin on mechanized tilt tables used to condition the crewmembers' cardiovascular system.

Heart rhythm disturbances have been seen among astronauts. Some of these may have been related to cardiovascular disease, but it is not clear whether this was due to pre-existing conditions or effects of space flight. It is hoped that advanced screening for coronary disease has greatly mitigated this risk. Other heart rhythm problems, such as atrial fibrillation, can develop over time, necessitating periodic screening of crewmembers' heart rhythms. Beyond these terrestrial heart risks, some concern exists that prolonged exposure to microgravity may lead to heart rhythm disturbances. Although this has not been observed to date, further surveillance is warranted.

Role of the ISS in quantifying the level of risk or acquiring additional information to confirm or eliminate risk.

ISS is required as the Mars transit analog for initial work to define “space normal” and subsequent countermeasure validation. Scientists will use the ISS to measure the time course of changes in cardiac structure and function over six months of spaceflight. They will define the potassium, magnesium, and phosphorus changes in relation to cardiovascular issues.

Progress in addressing the risk.

The Cardiovascular and Cerebrovascular Control on Return from ISS (CCISS) study looked at the effect of long-duration spaceflight on crewmembers' heart functions and their blood vessels that supply the brain. This experiment was a collaborative effort with CSA that utilized ISS from April 2007 through March 2010. By donning various devices and monitors as they went through various activities, crewmembers were able to give researchers information about their blood pressure, heart rate, and other important information about their cardiovascular systems while in microgravity. This data was compared with data obtained before launch and after landing. Overall, these data show no change in markers of cardiovascular stability during long-duration spaceflight and only relatively small changes post-flight in seated rest. The current program routine of countermeasures on ISS provided sufficient stimulus to maintain cardiovascular stability under resting conditions during long-duration spaceflight.

The Integrated Cardiovascular Study “Cardiac Atrophy and Diastolic Dysfunction During and After Spaceflight: Functional Consequences for Orthostatic Intolerance, Exercise Capacity, and Risk of Cardiac Arrhythmias” completed approximate 50% of the required subjects. This study will define the timecourse of cardiovascular changes in flight, as well as quantify the risk of cardiac Arrhythmias.

A new HHC study, Cardiovascular Oxidative Damage, was selected for flight on the ISS beginning in early 2013. Cardiovascular Oxidative Damage will identify biomarkers of oxidative and inflammatory stress and correlate them to indices of atherosclerosis risk before, during, and after long duration spaceflight.

Planned research to support	12	13	14	15	16	17	18	19	20
Risk of Cardiac Rhythm Problems									

3.14 Risk of Intervertebral Disc Damage (HHC)

Evidence from medical operations indicates that astronauts have a higher incidence of intervertebral disc (IVD) damage than the general population. Extended exposures to microgravity (and possibly fractional gravity) may lead to an increased risk of spinal nerve compression and back pain. Lengthening of the spine has been shown to occur during exposure to microgravity and may lead to IVD damage or other detrimental change to the IVD such as protrusion, herniation, degeneration or tear. Muscle weakness, muscle atrophy, and postural disturbances associated with exposure to microgravity may also be contributors. Although there appears to be a correlation between IVD damage and spaceflight, a causal relationship has yet to be definitively established.

Role of the ISS in quantifying the level of risk or acquiring additional information to confirm or eliminate risk.

Additional evidence will be gathered from ISS crewmembers in order to establish whether the lengthening of the spine exacerbates the risk for intervertebral damage with loading. The ISS will be used to determine the extent of this problem and guide design of re-entry and postflight protocols as well as future re-entry spacecraft. If significant issues are found, the ISS will be required to validate countermeasures. In addition, ISS is required as the Mars transit analog for countermeasure validation.

Progress in addressing the risk.

The Intervertebral Disc Damage (IVD) study, a NASA Research Announcement study selected in April 2009, was approved for flight by HRP in June 2011. The first subject is expected to launch in late 2012.



Figure 18. IVD test subjects will have upright MRI's taken of the lumbar region of the spine before and after flight.

The purpose of the study is to understand what causes spontaneous back pain during spaceflight and disc herniation after return to Earth. Investigators will describe disc structure and look for signs of tissue degradation before and after ISS missions to see if spaceflight might be causing changes that could lead to injury. State-of-the-art imaging technologies will be used to evaluate the lumbar discs of 12 astronauts before and after prolonged space flight.

Also, in early 2012, the Spinal Ultrasound study was selected for flight on ISS beginning in early 2013. Spinal Ultrasound will examine the anatomic and compositional changes in the vertebrae during long duration spaceflight. This study will introduce astronaut performed vertebral musculoskeletal ultrasound and allow a comparison to pre- and post-flight ultrasound and Magnetic Resonance Imaging (MRI). These in-flight components will capture the progression of changes and assist in the identification of causes. Currently, changes seen immediately

following spaceflight indicate a risk of Intervertebral Damage (IVD). However, because the etiology of the changes is unknown, this study will help to define the extent of the problem and its relationship to space exposure, which is presently a major knowledge gap in this area.

Planned research to support	12	13	14	15	16	17	18	19	20
Risk of Intervertebral Disc Damage									

3.15 Risk of Crew Adverse Health Event Due to Altered Immune Response (HHC)



Figure 19. Michael Fincke, Expedition 9 science officer, in Node 2 Harmony as he produces a wet saliva sample for the Integrated Immune experiment during Expedition 18.

Human immune function is altered during and after spaceflight, but it is unclear if this change leads to an increased susceptibility to disease. Reactivation of latent viruses has been documented in crewmembers, though this reactivation has not been directly correlated with the immune changes or with observed disease and is usually asymptomatic.

Role of the ISS in quantifying the level of risk or acquiring additional information to confirm or eliminate risk.

ISS will be used to investigate and validate the magnitude of immunosuppression as a result of space flight to ensure that the data represents space normal. The ISS will be used to develop and validate an immune monitoring strategy consistent with operational flight requirements and constraints including an inflight flow cytometer capable of various immunology/hematology measurements. The ISS will be used to develop and validate potential countermeasures (i.e., exercise, pharmaceutical or nutritional supplements) to mitigate any adverse effects of spaceflight on the immune system.

Progress in addressing the risk.

The Integrated Immune study completed its final in-flight activity and will now enter the data analysis phase. The final on-orbit samples were collected by the Expedition-30/31 crew and returned with the successful landing of Soyuz 29S on July 1, 2012. During this study, blood and saliva samples were collected on orbit, and returned ambient to Earth for terrestrial analysis. Blood samples were processed to determine peripheral leukocyte distribution, immunocyte function, cytokine production profiles, virus specific immunity, and physiological stress hormone levels. Saliva samples were processed to determine the latent herpesvirus reactivation and the circadian rhythm of cortisol. A total of 18 short duration and 17 long duration crewmembers participated in the study. Previous post-flight studies have routinely shown the dysregulation of the immune system, but it was unknown if this was an in-flight phenomenon. Preliminary Integrated Immune data indicates that immune system changes do occur and persist during long-duration spaceflight.

Planned research to support	12	13	14	15	16	17	18	19	20
Risk of Crew Adverse Health Event Due to Altered Immune Response									

3.16 Risk of Impaired Control of Spacecraft, Associated Systems and Immediate Vehicle Egress Due to Vestibular/Sensorimotor Alterations Associated with Space Flight (HHC)

It has been shown that long duration space flight alters vestibular/sensorimotor function which is manifested in some, but not all crewmembers (some have only partial symptoms while other show all) as changes in postural and locomotor control, gaze control, degradation of dynamic visual acuity, and perceptual changes. These changes have not been specifically correlated with real time performance decrements. The possible alterations in sensorimotor performance are of interest for Mars missions due to the prolonged microgravity exposure during transit followed by landing tasks. The risk of impairment is greatest during and soon after g-transitions when performance decrements may have high operational impact (landing, immediate egress following landing). This risk must be better documented and vestibular/sensorimotor changes must be better correlated with performance issues.

Role of the ISS in quantifying the level of risk or acquiring additional information to confirm or eliminate risk.

Since long-duration operational scenarios are still to be determined, the ISS will be used to gather the data required to define the research that might be needed to enable anticipated long-duration mission operations. This data includes the Space Station Remote Manipulator System, docking, glove box operations, Soyuz landings, and performance neurosensory dysfunction. If countermeasures for Mars missions are warranted, the ISS will be required as the Mars transit analog for CM validation.

The ISS will be used to determine individual capability for rapid sensorimotor adaptation, develop a sensorimotor adaptability training program that can be integrated into astronaut preflight exercise programs, and enhance inflight exercise programs to include sensorimotor adaptability component. The ISS will be used to collect data on crew performance during operationally relevant functional tasks and researchers will identify physiological systems that require countermeasures in order to preserve performance of functional tasks, as well as identify which physiological systems contribute the most to impaired performance on these functional tests.

The ISS will also be used to investigate volumetric, structural and functional changes in task-relevant brain structures and map changes in brain structures to changes in performance of cognitive and functional tasks. Results from this study would link changes in cognitive and functional performance with the degree of neuronal remodeling and determine if structural changes persist for an extended time period.

Progress in addressing the risk.

With the landing of STS-135, the Functional Task Test (FTT) project completed data collection on seven Shuttle crewmembers. The overall goals of the FTT are to determine the effects of space flight on functions that are representative of high-priority exploration mission tasks and to identify the key underlying physiological factors that contribute to decrements in performance.

FTT uses an interdisciplinary testing protocol that evaluates both astronaut functional performance and related physiological changes. Data collection and analysis of long-duration ISS crewmembers is still in progress.

New investigations recently selected for flight include assessments of operator control and perception of motion following 6 months in microgravity and changes in and recovery of neurocognitive performance.

Planned research to support	12	13	14	15	16	17	18	19	20
Risk of Impaired Control of Spacecraft, Associated Systems and Immediate Vehicle Egress Due to Vestibular/Sensorimotor Alterations Associated with Space Flight									

3.17 Risk of Performance Errors Due to Fatigue Resulting from Sleep Loss, Circadian Desynchronization, Extended Wakefulness, and Work Overload (BHP)



Figure 20. Expedition 14 flight engineer, Suni Williams, performs her daily tasks while wearing the Actiwatch device as seen on her left arm in the lower portion of this image

Reportedly, sleep loss has been an issue during spaceflight dating back to the Apollo missions. Research in current spaceflight scenarios using objective measures demonstrate that despite countermeasures, chronic sleep loss continues to exist on the Shuttle and the ISS. Fatigue resulting from sleep loss, circadian desynchronization, extended wakefulness and work overload occur to some extent for ground and flight crews, prior to and during spaceflight missions. Ground evidence indicates that fatigue, as experienced by ground and flight crews, may lead to performance errors, which could potentially compromise mission objectives, and consequently the mission itself.

Understanding the nature of sleep in space and developing mitigation strategies is therefore relevant in the current context and in preparing for future space missions. Efforts are needed to identify the environmental and mission conditions that interfere with sleep quality, as well as individual vulnerabilities to sleep loss and circadian desynchronization. Research areas to mitigate this risk may also include: development of a self-assessment tool for cognitive function and fatigue; light therapy for phase shifting, alertness and mood disorders; individualized protocols for sleep-wake medication use; sleep dose-response recovery curves and individualized models for countermeasure implementation and optimal work-rest schedules; and other evidence-based means to improve individual sleep quality and reduce fatigue.

Fatigue occurs during spaceflight and may jeopardize health and performance. This risk may be influenced by artificial and transmitted light exposure, individual vulnerability to sleep loss and circadian dynamics, and work/sleep schedules. Efforts are needed to improve sleep hygiene, and to identify and improve conditions that interfere with sleep quality.

Role of the ISS in quantifying the level of risk or acquiring additional information to confirm or eliminate risk.

The ISS will be used to assess artificial and transmitted light exposure on performance, to quantify individual vulnerability to sleep loss, circadian dynamics, work/sleep schedules, subjective work overload, and the effects of sleep/wake medications. The ISS will be used to collect data and subsequently validate a self-assessment tool for cognitive function and fatigue; light therapy for phase shifting, alertness and mood disorders; and other means to improve sleep quality and reduce fatigue. The ISS is required to investigate the sleep-related issues associated with microgravity, and to ensure that the tools and methods are appropriate for the spaceflight environment.

Progress in addressing the risk.

The BHP completed the Sleep/Wake actigraphy investigation and is working to incorporate methods and protocols for monitoring sleep into routine medical operations. Data from this study, as well as from ground-based lighting studies, also contributed to new requirements for the upgraded Solid State Lighting Assemblies (SSLAs) targeted for installation on ISS beginning in 2015. The results of the studies convinced ISS management to incorporate specific lighting capabilities to allow much better circadian entrainment of the crew and provide the ability for research to utilize the lighting system to develop future circadian countermeasures.

The “Reaction Self Test” investigation developed a 3-minute Psychomotor Vigilance Test (PVT) to serve as both a data collection measure and an operationally relevant tool, offering astronauts a quick way to assess their own performance acuity before they perform critical tasks. The PVT began in flight implemented in 2009, and data acquisition began with ISS Expedition 21-22. As of the end of 2011, in-flight data acquisition was underway or had been completed on 12 astronauts, with a total of 864 Reaction Self Tests performed in flight or an 85% adherence rate.

Planned research to support	12	13	14	15	16	17	18	19	20
Risk of Performance Errors Due to Fatigue Resulting from Sleep Loss, Circadian Desynchronization, Extended Wakefulness, and Work Overload									

3.18 Risk of Bone Fracture (HHC)

Bone mineral loss occurs in microgravity due to unloading of the skeletal system, with average loss rates of approximately 1% per month. It is unclear whether this bone mineral density will stabilize at a lower level, or continue to diminish. It is also unknown if fractional gravity, present on the moon and Mars would mitigate the loss. This level of bone loss does not create an unacceptable risk of fractures for ISS missions, but longer missions could create higher fracture risk. The risk of fracture during a mission cannot be accurately estimated until mechanisms and probabilities of bone overloading during the missions are understood. This risk deals specifically with the risk of one fracture during an exploration mission.



Figure 21. Bill McArthur, Expedition 12 science officer, during check out of the SLAMMD hardware of HRF-2. Measuring the mass of a crewmember in space is difficult because mass does not equal weight in the absence of gravity.

Role of the ISS in quantifying the level of risk or acquiring additional information to confirm or eliminate risk.

Pre, in, and post-flight data will be gathered from ISS crews to validate and/or update the current Space Human Health bone standard. Validated technologies to monitor changes in bone quality for use in spaceflight applications will be delivered and follow-on ISS studies will be used to flight-validate the technology. A flight study will be conducted to assess spine health pre and post ISS missions. The initial measures will determine if there are vertebral compression fractures in returning crew. The ISS will be used to validate an

exercise regimen effective at mitigating physiological decline in space and preserving human performance capacity in crewmembers serving on long-duration missions.

Progress in addressing the risk.

In January 2010, the first on-orbit operations for the Pro K, “Dietary Intake Can Predict and Protect Against Changes in Bone Metabolism During Spaceflight and Recovery”, flight investigation were executed by the first subject onboard the ISS. Pro K is an HRP flight investigation which proposes that a diet with a decreased ratio of animal protein to potassium will lead to decreased bone resorption and decreased percentage of bone mineral loss during flight. The goals for this experiment are:

- 1) to validate the hypothesis that modification of dietary intake patterns can minimize bone loss and post-flight recovery time by determining if the ratio of acid (animal protein) to base (potassium) precursors in the diet is correlated with markers of bone formation and bone resorption during spaceflight;
- 2) to determine the extent to which urinary calcium excretion predicts changes in bone metabolism from acid and base precursors in the diet;
- 3) to determine if the ratio of acid to base precursors in the diet is related to the length of time required for recovery from bone mineral loss after spaceflight; and
- 4) to develop a dietary countermeasure for bone loss that has no associated risks for side effects, no requirements for payload mass, and no additional crew time necessary during flight.

This data could provide the necessary foundation to make dietary recommendations to minimize the extent of bone loss during space flight exploration. The last subjects are scheduled for flight in FY 2013.

Planned research to support	12	13	14	15	16	17	18	19	20
Risk of Bone Fracture									

3.19 Risk of Renal Stone Formation (HHC)

Urinary biochemistry experiences changes during space flight, presenting the possibility that symptomatic renal stones may form, resulting in urinary calculi or urolithiasis, renal colic (pain), nausea, vomiting, hematuria, infection, hydronephrosis. Kidney stone formation and passage has the potential to greatly impact mission success and crewmember health for long duration missions. Alterations in hydration state (relative dehydration) and bone metabolism (increased calcium excretion) during exposure to microgravity may increase the risk of kidney stone formation and it is unclear which mitigation strategy would be the most effective.



Figure 22. ISS Expedition 13 flight engineer, Thomas Reiter, on board ISS processes samples for the Renal Stone investigation

Space normal must first be defined for this risk. The evidence establishing the risk factors and/or the likelihood of risk occurrence for renal stone formation is either known or in progress. The activities in this area are intended to compile data related to the risk of renal stone formation, from medical data and from raw research data used for previously published reports. From these data, the task is to determine primary and other risk factors for renal stone formation, particularly regarding the types of stones formed (to identify the specific risk factor and appropriate countermeasure), the correlation with diet, and the time course for formation. Ground data mining and final analysis of the previous Renal Stone Flight Study will be used to determine if further work is warranted for this risk.

Role of the ISS in quantifying the level of risk or acquiring additional information to confirm or eliminate risk.

The ISS will be used to take the next step in understanding the stone-forming risk crewmembers experience during and after space flight. The ISS will be used to determine the influence of urinary calcium excretion on the predictability of changes in bone metabolism from acid and base precursors in the diet. Data collected on ISS will be used to determine a relationship between urinary calcium excretion and renal stone formation. Based on the known increased risk crewmembers experience, it is important to develop and test countermeasures to reduce or alleviate this risk. ISS is required as the Mars transit analog for countermeasure validation if countermeasures other than potassium citrate are needed.

Progress in addressing the risk.

Following completion of the Renal Stone CM investigation, flight operations, and data analysis in 2008, the JSC Chief Medical Officer approved proceeding to transition the potassium citrate recommendation to medical operations. In June 2009, the NASA Headquarters Office of the Chief Health and Medical Officer (OCHMO) conducted an operational readiness review of the potassium citrate countermeasure for the prevention of renal stones in spaceflight. The expert review panel unanimously recommended that the countermeasure be approved for operational use. On June 30, 2009, the NASA Headquarters OCHMO issued a memo formally approving operational use of this countermeasure.

The results of this research investigation provided a potential countermeasure to a major health concern of the Program. The findings of the investigation were documented in the Journal of Urology in November 2009. Although the countermeasure has transitioned to operations, additional countermeasures are under investigation to provide flight surgeons more options for reducing the risk of renal stones. Investigations aimed at reducing bone loss will also contribute to reductions in the likelihood of renal stone formation.

Planned research to support	12	13	14	15	16	17	18	19	20
Risk of Renal Stone Formation									

3.20 Risk of Spaceflight-Induced Intracranial Hypertension/Vision Alterations (HHC)

Some crewmembers on long duration ISS missions experienced ophthalmic anatomical changes and visual performance decrements of varying degrees which were temporary in some cases and permanent in others. Research has demonstrated a high probability that all astronauts have idiopathic intracranial hypertension to some degree.



Figure 23. European Space Agency astronaut Paolo Nespoli (foreground) and NASA astronaut Ron Garan, both Expedition 27 flight engineers, perform the Health Maintenance System (HMS) Eye Exam - PanOptic in the Destiny laboratory of the ISS.

Visual acuity changes and visual field defects occur at a rate much higher than expected in spaceflight crews. Observed physical findings in long-duration crewmembers include papilledema, choroidal folds, increased optic nerve sheath diameter, and a posterior flattened globe. Persistent increased post-flight intracranial pressure (ICP) has been inferred in several cases, consistent with a root cause of intracranial hypertension (IHT) possibly secondary to microgravity-induced fluid shifts. The mechanisms that cause IHT in microgravity are not known, and the processes by which eye damage occurs as a result of IHT are not well understood. Decreased visual acuity, IHT, and other findings are present months, and in some cases years, after return, indicating that damage may be permanent.

Acuity changes have been noted in short-duration crewmembers, indicating that the process starts early in spaceflight, although this group has not been closely examined. It is unknown if fractional gravity would mitigate the hazard, but its persistence after return to Earth suggests not. Likewise, the impact of multiple missions or of cumulative time in space is not yet established. Greater understanding of the mechanisms for eye damage and IHT is necessary to understand and mitigate the hazard and treat the resultant conditions.

Progress in addressing the risk.

On December 19-20, 2011, the HRP, along with the JSC Chief Medical Officer, conducted a Research and Clinical Advisory Panel (RCAP) for the Visual Impairment/Intracranial Pressure (VIIP) risk. The purpose of the RCAP was to review and provide analysis to NASA on the direction, status, and progress of research and clinical activities intended to mitigate the VIIP issues during and after spaceflight. Initial recommendations from the panel were incorporated into the VIIP Research Plan that was approved by HRP in July 2012. Initial investigation utilized routine operational data to inform the need for future research, and a new investigation to extend the operational monitoring protocol was recently selected for flight implementation.

In April 2012, HRP made selections from the responses to “Research and Technology Development to Support Crew Health and Performance in Space Exploration Missions - NNJ11ZSA002NA.” Among the areas of focus in this solicitation is the high priority research area in visual impairment and intracranial pressure. NASA awarded 14 researchers for this solicitation, four of which address the VIIP risk.

Planned research to support	12	13	14	15	16	17	18	19	20
Risk of Spaceflight-Induced Intracranial Hypertension/Vision Alterations									

3.21 Risk of Adverse Health Effects Due to Alterations in Host-Microorganism Interactions (SHFH)



Figure 24. Kenneth D. Bowersox, Expedition 6 mission commander, uses the water microbiology kit (WMK) to collect water samples for in-flight chemistry/microbiology analysis in the Destiny laboratory on the ISS.

Negative impacts from microorganisms during space flight are not uncommon; but major consequences to crew health and performance fortunately have been infrequent compared to the general public. Because consequences of infectious disease could include loss of mission and loss of crew, recent findings that spaceflight can increase virulence of microorganisms indicates that the extent of the risk of adverse health effects due to infectious disease or allergic response may be greater than previously expected. Therefore additional characterization of the determinant of infectious disease in long duration missions is imperative if mitigation strategies are to be sufficiently robust to ensure crew health and mission success.

Role of the ISS in quantifying the level of risk or acquiring additional information to confirm or eliminate risk.

The ISS will be used to evaluate changes in host and microbial cellular response to the spaceflight analog and spaceflight, assess the likelihood and consequence of risk to crew health that is posed by increases in virulence of microbial pathogens as they are exposed to conditions of space travel, and determine if changes in crew flora is occurring during a spaceflight.

Progress in addressing the risk.

SHFH partnered with personnel from the University of Texas Health Science Center at Houston to review ISS water systems and historical monitoring data to evaluate the current potable water systems and assess the risk to the crew. The technique, called “quantitative microbial risk assessment,” uses sophisticated mathematical models to determine risks. The evaluation found that while the risk to the crew was not significantly higher than the risk of drinking water from a drinking well or municipal system, many factors increased the uncertainty. Among these factors are the high potential for biofilm formation, disruption of the immune system and changes in microbial virulence. In addition, the reliance of the crew on only one or two water sources also increased the risk that contamination could result in crew illness. This evaluation marks the first study to begin quantifying the microbial risks associated with long-duration spaceflight and establishes a foundation from which to target key factors to mitigate those risks.

Planned research to support	12	13	14	15	16	17	18	19	20
Risk of Adverse Health Effects Due to Alterations in Host-Microorganism Interactions									

3.22 Risk of Decompression Sickness



Figure 25. Lunar EVA conditions may be more stressful than current Shuttle or ISS conditions, which could increase the risk of decompression sickness (DCS). Further studies are recommended to evaluate the risk of DCS in these scenarios.

As NASA’s future for human exploration expands beyond low Earth orbit, life-support systems for spacecraft and EVA suits will need to be scaled appropriately for available resources, mission operations, and atmospheric composition. These tradeoffs may pose a greater risk of decompression sickness (DCS) for the EVA crewmember if parameters such as prebreathe duration, oxygen concentration, or suit pressure are altered from those used in the past. As a result, anticipated atmospheric conditions for exploration vehicles and EVA suits will require careful evaluation for their potential risks to the crew.

As part of an effort to establish the risk of DCS during exploration missions, HRP commissioned a panel of external experts to review the risk of DCS for lunar missions and provide recommendations regarding the likelihood and consequence of the risk and any

applicable forward work to understand and mitigate the risk. The panel was instructed to review a set of proposed lunar mission scenarios and timeframes for which DCS may be a risk: acute health, trauma during launch and landing, impact on mission operations, and post-mission long-term health concerns.

Progress in addressing the risk.

Scientists will study venous gas emboli (VGE) and gaseous nitrogen (N₂) elimination to determine whether the onset time and incidence of VGE and rate of N₂ elimination is different in microgravity compared to 1-g after depressurization. Additional research requirements are under development to address planned exploration operations.

Planned research to support is TBD	12	13	14	15	16	17	18	19	20
Risk of Decompression Sickness									

3.23 Risk of an Incompatible Vehicle/Habitat Design (SHFH)



Figure 26. NASA astronaut Tracy Caldwell Dyson, Expedition 24 flight engineer, looks through a window in the Cupola of the ISS. A blue and white part of Earth and the blackness of space are visible through the windows.

The habitability of space architectures and pressurized environments, and the usability of tools and equipment is critical for the existence of humans in space. Any inadequacies in the design of the environment can restrict or prevent the user from surviving in extreme conditions and may impact safety and performance. Factors that affect the habitability must be assessed and properly addressed to ensure all potential hazards are mitigated or monitored. The improper planning and design of space environments introduces the possibility of errors or decreases the ability of the crew to complete tasks in a timely manner. Inconsistent design among subsystems and vehicles leads to negative transfer of training and increases risks.

Role of the ISS in quantifying the level of risk or acquiring additional information to confirm or eliminate risk.

Designing habitable environments in confined, isolated, and unforgiving conditions, restricted by launch capability, and mass and power constraints is difficult. The ISS is a perfect platform to provide insight to future space habitat designs and will be used to evaluate the effect of architecture on crew performance including how net habitable volume, functional layout, and traffic patterns affect the crew; the effects of environmental factors on crew performance including how lighting, noise, temperature, air flow, or other environmental factors affect the crew; and the effects of time for self-sustaining activities including how time for personal hygiene, meals, recreation, medical conferences, family conferences, and other non-operational activities affect crew safety and performance.

The physiological response of the human body to micro-gravity presents challenges to spacecraft, spacesuit and equipment designers. Historical data indicates that spinal elongation occurs when crewmembers are subjected to microgravity. In as little as two days, the typical crewmember will exhibit increases in stature of up to 3 percent. However, to date data has been collected only for crewmembers in standing postures, and a limited pool of subjects was available. Seated height data in microgravity is considered necessary to identify correctly the seated height projections of the crew for future spacecraft configurations. Additionally, data concerning the effects of spinal elongation on seated height would aid in the design of suit components, as well as requirements for habitats and other vehicles. The ISS will be used to collect seated height due to spinal growth for subjects exposed to microgravity environments and seated height rate of change over time.

Progress in addressing the risk.

The Spinal Elongation and its Effects on Seated Height in a Microgravity Environment study provided quantitative data as to the amount of change that occurs in the seated height due to spinal elongation in microgravity. ISS was utilized to support this study from March 2009 to September 2011. Data was collected from 29 ISS and Shuttle crewmembers and included digital pictures and seated height measurements taken before, during, and after flight. Additionally, stature measurements were obtained from 23 of the 29 crewmembers. The results showed that participating crewmembers experienced growth up to 6% in seated height and up to 3% in stature. A recommended growth allowance of 6% for seated height, based on the analysis of the subject data, will be provided to vehicle designers as the necessary seated height adjustment to allow for crew exposure to microgravity.

Planned research to support	12	13	14	15	16	17	18	19	20
Risk of an Incompatible Vehicle/Habitat Design									

4. Summary

In summary, the ISS remains an invaluable asset in addressing human risks sufficiently to enable NASA to safely proceed with mission goals and objectives. It will be used through 2020 to complete the studies necessary to understand the severity of certain risks, to gather evidence to quantify the risks, and to complete the development of key countermeasures. The ISS research allows validation of techniques and technologies needed for long duration flight with particular interest in the transit phase of a Mars mission.

		12	13	14	15	16	17	18	19	20
3.1	Risk of Unacceptable Health and Mission Outcomes due to Limitations of In-Flight Medical Capabilities									
3.2	Risk Factor of Inadequate Nutrition									
3.3	Risk of Performance Decrements and Crew Illness Due to an Inadequate Food System									
3.4	Risk of Adverse Behavioral Conditions and Psychiatric Disorders									
3.5	Risk of Radiation Carcinogenesis from Space Radiation									
3.6	Risk of Compromised EVA Performance and Crew Health Due to Inadequate EVA Suit Systems									
3.7	Risk of Early Onset Osteoporosis Due to Spaceflight									
3.8	Risk of Orthostatic Intolerance During Re-exposure to Gravity									
3.9	Risk of Impaired Performance Due to Reduced Muscle Mass, Strength and Endurance									
3.10	Risk of Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity									
3.11	Risk of Clinically Relevant Unpredicted Effects of Medication									
3.12	Risk of Performance Decrements Due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team									
3.13	Risk of Cardiac Rhythm Problems									
3.14	Risk of Intervertebral Disc Damage									
3.15	Risk of Crew Adverse Health Event Due to Altered Immune Response									
3.16	Risk of Impaired Control of Spacecraft, Associated Systems and Immediate Vehicle Egress Due to Vestibular/Sensorimotor Alterations Associated with Space Flight									
3.17	Risk of Performance Errors Due to Fatigue Resulting from Sleep Loss, Circadian Desynchronization, Extended Wakefulness, and Work Overload									
3.18	Risk of Bone Fracture									
3.19	Risk of Renal Stone Formation									
3.20	Risk of Spaceflight-Induced Intracranial Hypertension/Vision Alterations									
3.21	Risk of Adverse Health Effects Due to Alterations in Host-Microorganism Interactions									
3.22	Risk of Decompression Sickness									
3.23	Risk of Incompatible Vehicle/Habitat Design									

Table 3
Summary of HRP Risks Being Addressed Using ISS by FY

Note: Data derived from the Sept/Oct 2011 analysis (by ISSMP) of flight experiments identified in the IRP, Rev C and associated discussions with HRP Elements.

Appendices

Appendix A: Cross-reference of Risks and Tasks (Experiments)

This table traces the HRP risk to the IRP Rev C investigation associated with HRP “Fly-off Plan” experiment title and shows the required number of subjects (“N”) that are being accommodated or remain unmet. ISS increments are indicated within fiscal years. An “L” indicates the launch of experiment hardware. Some experiments do not require Human subjects, but do require crew time for set-up and other operational activities.

Sec No	HRP Risk with Tasks on ISS	Associated Tasks		FY	12	13	14	15	16	17	18	19	20	"N"			
		IRP Rev C Title	Fly-off Plan Title	Subj Req	129-32	133-36	137-40	141-44	145-48	149-52	153-56	157-60	161-64	Unmet			
3.1	Risk of Unacceptable Health and Mission Outcomes Due to Limitations of In-flight Medical Capabilities	a	Risk of Intervertebral Disc Damage After Prolonged Spaceflight	Intervertebral Disk Damage/Hargens (p/p)	12	0 0	1 1	2 1	2 1	2 1	1 0				0		
		b	Development of Methods/Technologies for Eye Wash	Eye Wash (ExMC)	N/A					0 0 0	0 0 0	L 1 0				0	
		c		Flexible Ultrasound (ExMC)	N/A					0 0	0 0	L 1 0				0	
		d	ISS Flight Demonstration of Oxygen Concentrator	O2 Concentrator (ExMC)	N/A						0 0	0 0	L 1 0			0	
		e	Development of Methods/Technologies to Auscultate and Capture Body Sounds in a Noisy Environment	Auscultate (ExMC)	N/A	0 0 0	L 1 0										0
		f	Development of Methods/Technologies for Treating MLT	MLT Injury (ExMC)	N/A							0 0 0	0 0 0	L 1 0		0	
		g	Development of Methods/Technologies for Dental Conditions	Advanced Dental (ExMC)	N/A					0 0 0	L 1 0						0
		h		On-Orbit Analysis (HHC Tech Dev.)	N/A			0 0	0 L	1 0							0
		i		Advanced Biomed Sensors (ExMC)	N/A				0 0	0 L	1 0						0
		j	Sonographic Astronaut Vertebral Examination	Sonogram-Vertebral/Dulchavsky (NxPCM)	12	0 0	0 3	2 3	2 2	0							0
		k	Exploration Medical System Demonstration on ISS	Exploration Medical Demo (ExMC)	N/A			0 0 0	L 1 0								0
3.2	Risk Factor of Inadequate Nutrition	a	Nutritional Status Assessment: SMO 016E	Nutrition/SMO-016E/Smith	30	2 3	2 0								0		
		b	Dietary Intake Can Predict and Protect Against Changes in Bone Metabolism During Space Flight and Recovery (Pro-K)	Pro K/Smith	16	2 3	3 3	0								0	
		c	Integrated Resistance and Aerobic Training Study	Sprint (Active Subjects)/Ploutz-Snyder	12	1 1	1 1	1 1	1 1	1 1	1 0					0	
				Sprint (Control Subjects)/Ploutz-Snyder	6	0 1	0 1	0 1	0 1	0 1	0 1	0				0	
		d	Occupational Risk Surveillance for Bone	Bone Risk Surveillance (p/p) (NxPCM)	6		0 0 0	2 2	2 0							0	
		e	Exercise Plus Nutritional Supplement Studies	Exercise + Supplements (ECP)	12											12	
f	Oxidative Damage Study	Oxidative Damage Follow-On (NxPCM)	12								0 0 0	2 1	9				
3.3	Risk of Performance Decrement and Crew Illness Due to an Inadequate Food System	a	Factors Contributing to Food Acceptability and Consumption, Mood, and Stress on Long-term Space Missions	Food Acceptability Factors/Vickers (SHFH)	10		0 0 0	1 2	3 2	2 0					0		
		b	Understanding the Effects of Microgravity on Taste	Taste in Microgravity (SHFH)	15			0 0 0	3 2	3 2	3 2	0			0		

Sec No	HRP Risk with Tasks on ISS	Associated Tasks		FY	12	13	14	15	16	17	18	19	20	"N"	
		IRP Rev C Title	Fly-off Plan Title	Subj Req	129-32	133-36	137-40	141-44	145-48	149-52	153-56	157-60	161-64	Unmet	
3.4	Risk of Adverse Behavioral Conditions and Psychiatric Disorders	a	Behavioral Issues Associated with Long Duration Space Missions: Review of Astronaut Journals	Journals (6-crew)/Stuster	10	2 2	2 2	2 2	θ					0	
		b	ISS Validation of all tools from BMed Gap2	Monitoring/CM Tools&Tech (BHP)	24									24	
3.5	Risk of Radiation Carcinogenesis	Ongoing data collection during nominal operations			Ongoing data collection during nominal operations										
3.6	Risk of Compromised EVA Performance and Crew Health Due to Inadequate EVA Suit Systems	a	Data from ISS EVAs will be used to optimize suit designs and determine metabolic		N/A									N/A	
		b	Prevalence of Venous Gas Emboli after Depressurization in Microgravity	VGE in Microgravity (NxPCM)	12					θ θ	θ	1 1 2	1 1	1 1	4
3.7	Risk of Early Onset Osteoporosis Due To Spaceflight	a	Bisphosphonates as a Countermeasure to Space Flight Induced Bone Loss: SMO-021	Bisphosphonates/E255-SMO021/Matsumoto-Leblanc	7	θ								0	
		b	Bisphosphonates as a Countermeasure to Space Flight Induced Bone Loss: SMO-021	Bisphosphonates Controls/E255-SMO021/Matsumoto-Leblanc	10	θ	2 1 2	1 2	1 1	θ					0
		c	Biomechanical Analysis of Treadmill Locomotion on the ISS	Treadmill Kinematics/DeWitt	6	3 2	θ								0
		d	Nutritional Status Assessment: SMO 016E	Nutrition/SMO-016E/Smith	30	2 3	2 θ								0
		e	Dietary Intake Can Predict and Protect Against Changes in Bone Metabolism During Space Flight and Recovery (Pro-K)	Pro K/Smith	16	2 3	3 3	θ							0
		f	Integrated Resistance and Aerobic Training Study	Sprint (Active Subjects)/Ploutz-Snyder	12	1 1	1 1	1 1	1 1	1 1	1 θ				0
				Sprint (Control Subjects)/Ploutz-Snyder	6	θ 1	0 1	0 1	0 1	0 1	0 1	θ			0
		g	Occupational Risk Surveillance for Bone	Bone Risk Surveillance (p/p) (NxPCM)	6		θ θ θ	2 2	2 θ						0
		h	Bone Countermeasure Study	Bone Countermeasure Study (NxPCM)	12							0 0	0 2	2 2	6
		i	Exercise Plus Nutritional Supplement Studies	Exercise + Supplements (ECP)	12										12
		j	Bone Loss Therapy - TBD	Bone Loss Therapy (NxPCM)	24										24
k	Ground-based Biomechanical Analyses of Resistance Exercise Using the Advanced Resistive Exercise Device	ARED Kinematics	0										0		
3.8	Risk of Orthostatic Intolerance During Re-Exposure to Gravity	a	Cardiac Atrophy and Diastolic Dysfunction During and After Long Duration Spaceflight: Functional Consequences for Orthostatic Intolerance, Exercise Capacity, and Risk of Cardiac Arrhythmias	Integr. CV /E377/Bungo-Levine	12	3 3	1 θ							0	

Sec No	HRP Risk with Tasks on ISS	Associated Tasks		FY	12	13	14	15	16	17	18	19	20	"N"		
		IRP Rev C Title	Fly-off Plan Title	Subj Req	129-32	133-36	137-40	141-44	145-48	149-52	153-56	157-60	161-64	Unmet		
3.10 cont.	Risk of Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity	c	Integrated Resistance and Aerobic Training Study	Sprint (Active Subjects)/Ploutz-Snyder	12	1 1	1 1	1 1	1 1	1 1	1 0				0	
			Sprint (Control Subjects)/Ploutz-Snyder	6	0 1	0 1	0 1	0 1	0 1	0 1	0 1	0				0
		d	Development of New Exercise Hardware for Exploration Missions	Sprint Optimization w/New Exer HW (ECP)	12				0 0 0	0 L	0 1	1 2	1 2	1 2	1 2	2
			e		SPRINT Optimization Studies											
		f	Exercise Plus Nutritional Supplement Studies	Exercise + Supplements (ECP)	12											12
		g	Ground-based Biomechanical Analyses of Resistance Exercise Using the Advanced Resistive Exercise Device	ARED Kinematics	0											0
3.11	Risk of Clinically Relevant Unpredicted Effects of Medication	a	Determine Efficacy of Antimicrobial Agents in the Medops Kit Against Microbes That Have Undergone Virulence Changes Seen in Spaceflight Analogs	Efficacy of Antimicrobials (NxPCM)	N/A			0 0	0 L	1 0					0	
		b	MSTT Flight Validation	Medication/Symptom Tracking Tool - MSTT (NxPCM)	24						0 0	0 2	2 3	2 3	12	
		c	Determine Effect of Spaceflight Environment on Drug Distribution and Metabolism	Metabolism in Spaceflight (NxPCM)	30										30	
3.12	Risk of Performance Decrements Due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team	a	BHP ISS Utilization Study	Cross Cultural Teams/Miller (BHP)	6		0 0	0 2	3 1	0 0					0	
		b	Assessing the Impact of Communication Delay on Performance: An Examination of Autonomous Operations Utilizing the ISS (IStar Pilot)	Comm Delay (BHP)	20	0 0	0 3	1 3	2 3	2 3	2 3	1 0				
		c	Factors Contributing to Food Acceptability and Consumption, Mood, and Stress on Long-term Space Missions	Food Acceptability Factors/Vickers (SHFH)	10		0 0	0 1	2 2	3 2	2 0				0	
		d	Impact of Increased Work Autonomy on Performance	Teams in Autonomous Environments/Tannenbaum (BHP)	25				0 0	0 3	2 2	3 2	3 2	3 2	3	

Sec No	HRP Risk with Tasks on ISS	Associated Tasks		FY	12	13	14	15	16	17	18	19	20	"N"			
		IRP Rev C Title	Fly-off Plan Title	Subj Req	129-32	133-36	137-40	141-44	145-48	149-52	153-56	157-60	161-64	Unmet			
3.13	Risk of Cardiac Rhythm Problems	a	Cardiac Atrophy and Diastolic Dysfunction During and After Long Duration Spaceflight: Functional Consequences for Orthostatic Intolerance, Exercise Capacity, and Risk of Cardiac Arrhythmias	Integr. CV /E377/Bungo-Levine	12	3	3	1	0						0		
		b	Nutritional Status Assessment: SMO 016E	Nutrition/SMO-016E/Smith	30	2	3	2	0							0	
		c	Defining the relationship between biomarkers of oxidative and inflammatory stress and atherosclerosis risk in astronauts during and after long-duration spaceflight	Cardiovasc. Ox. Damage/Platts	12	0	0	0	2	2	2	2	2	0			0
		d	In flight fluid distribution	Inflight Fluid Distribution (HHC/VIIP)	12				0	0	0	3	2	3	2	2	0
3.14	Risk of Intervertebral Disk Damage	a	Risk of Intervertebral Disc Damage After Prolonged Spaceflight	Intervertebral Disk Damage/Hargens (p/p)	12	0	0	1	1	2	1	2	1	2	1	1	0
		b	Sonographic Astronaut Vertebral Examination	Sonogram-Vertebral/Dulchavsky (NxPCM)	12	0	0	0	3	2	3	2	2	0			0
3.15	Risk of Crew Adverse Health Event Due to Altered Immune Response	a		UMS Checkout	N/A	0										0	
		b	Validation of Procedures for Monitoring Crewmember Immune Function (Integrated Immune - SMO 015/SDBI 1900)	Integrated Immune/SMO-015/Sams	17	3	0										0
		c	Nutritional Status Assessment: SMO 016E	Nutrition/SMO-016E/Smith	30	2	3	2	0								0
		d	The Effects of Long Term Exposure to Microgravity in Salivary Markers of Innate Immunity [in IRP RevC]	Salivary Markers/Simpson (NxPCM)	6	0	0	0	2	2	2	0					0
		e	Determine Efficacy of Antimicrobial Agents in the Medops Kit Against Microbes That Have Undergone Virulence Changes Seen in Spaceflight Analogs [in IRP RevC]	Efficacy of Antimicrobials (NxPCM)	N/A				0	0	0	L	1	0			0

Sec No	HRP Risk with Tasks on ISS	Associated Tasks		FY	12	13	14	15	16	17	18	19	20	"N"	
		IRP Rev C Title	Fly-off Plan Title	Subj Req	129-32	133-36	137-40	141-44	145-48	149-52	153-56	157-60	161-64	Unmet	
3.15 cont.	Risk of Crew Adverse Health Event Due to Altered Immune Response	f	Investigation of the Role of Increased Body Iron Stores on Immune Function and Viral Reactivation	Iron Stores (NxPCM)	12				0 0	0 3	2 3	2 2	0	0	
		g	What is the Interrelationship of Nutritional Status and Immune System Function During Flight	Nutrition & Immune System (NxPCM)	12				0 0	0 1	3 2	3 2	1 0	0	
		h		Flow Cytometer (ExMC)	N/A						0 0 0	L 1 0	0		
		i	Immune Countermeasures Development - In-flight Validation	Immune Countermeasure Flight Valid. (NxPCM)	17						0 0 0	2 3	2 2	8	
3.16	Risk of Impaired Control of Spacecraft, Associated Systems and Immediate Vehicle Egress Due to Vestibular/Sensorimotor Alterations Associated with Space Flight	a	Physiological Factors Contributing to Postflight Changes in Functional Performance (Bloomberg)	Functional Task Test (FTT)/Bloomberg	13	1 2	1 2	1 2	0					0	
		b	Assessment of Operator Proficiency Following Long-Duration Spaceflight (Moore) / Effect of Sensorimotor Adaptation Following Long-Duration Spaceflight on Perception and Control of Vehicular Motion (Wood)	Manual Control (pre/post only)/Moore	8	0 0	2 1	2 1	2 0					0	
		c	Spaceflight Effects on Neurocognitive Performance: Extent, Longevity, and Neural Bases	Neurocognitive Performance/Seidler (NxPCM+BHP)	13	0 0 0	1 2	1 2	1 2	1 2	1 0				
		d	Development of Countermeasures to Enhance Sensorimotor Adaptation (Bloomberg)	SM Adaptation/Bloomberg (NxPCM)	12		0 0 0	1 1	2 2	1 2	1 2	1 1	1 0	0	
		e	Evaluating Early Changes in Sensorimotor Function after Long-Duration Spaceflight	Sensorimotor Field Test (p/p) (HHC/NxPCM)	15				0 0	0 1	2 1	2 1	2 1	2 1	2
		f	Developing Predictors of Sensorimotor Adaptability - ISS Flight Validation	Adaptability Assessment (NxPCM)	15					0 0 0	2 1	2 1	2 2	5	

Sec No	HRP Risk with Tasks on ISS	Associated Tasks		FY	12	13	14	15	16	17	18	19	20	"N"	
		IRP Rev C Title	Fly-off Plan Title	Subj Req	129-32	133-36	137-40	141-44	145-48	149-52	153-56	157-60	161-64	Unmet	
3.19	Risk of Renal Stone Formation	a	Nutritional Status Assessment: SMO 016E	Nutrition/SMO-016E/Smith	30	2 3	2 0							0	
		b	Dietary Intake Can Predict and Protect Against Changes in Bone Metabolism During Space Flight and Recovery (Pro-K)	Pro K/Smith	16	2 3	3 3	0						0	
		c	Integrated Resistance and Aerobic Training Study	Sprint (Active Subjects)/Ploutz-Snyder	12	1 1	1 1	1 1	1 1	1 1	1 0				0
				Sprint (Control Subjects)/Ploutz-Snyder	6	0 1	0 1	0 1	0 1	0 1	0 1	0			0
		d	Occupational Risk Surveillance for Bone	Bone Risk Surveillance (p/p) (NxPCM)	6		0 0	0 0	2 2	2 0					0
		e	Exercise Plus Nutritional Supplement Studies	Exercise + Supplements (ECP)	12										12
3.20	Risk of Spaceflight-Induced Intracranial Hypertension/Vision Alterations (VIIP)	Research associated to this risk is under development		Research associated to this risk is under development											
		a	VIIP Placeholder - Monitoring Protocol (HHC/VIIP)	12	0 0 0	2 1	3 2	3 1	0					0	
		b	VIIP Placeholder - Fluid CM (HHC/VIIP)	12						0 0	0 0	1 1	2 2	6	
3.21	Risk of Adverse Health Effects Due to Alterations in Host-Microorganism Interactions	a	Host-Microbe Virulence – Crew	Virulence-Crew (SHFH) - FA in work	6	0 0	0 2	2 2	0					0	
		b	Host-Microbe Virulence – Cellular Studies	Virulence-Cell (SHFH)	N/A		0 0 0	1 1	0					0	
3.22	Risk of Decompression Sickness	a	Habitability - Human Factors & Habitability Assessment Tool	Hab Assessment/Thaxton (SHFH)	Research associated to this risk is under development										
3.23	Risk of Incompatible Vehicle/Habitat Design	a	Habitability - Human Factors & Habitability Assessment Tool	Hab Assessment/Thaxton (SHFH)	6	0 0 0	2 2	2 0						0	
*	Not assigned to a Risk-Repository/ McMonigal	a	ExMC Infrastructure Activity	Repository/McMonigal	As many as possible	2 3	3 3	3 3	3 3	3 3	3 3	3 3	3 3	N/A	

**Table 5.1
Cross-reference of HRP Risks with Their Associated Tasks on ISS**

Appendix B: Select Products and Publications from ISS

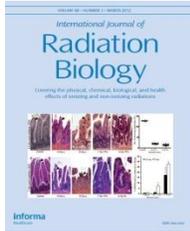
Sample Results from ISS Research

1. NASA HRP research has shown that bone loss from space flight does not recover to its normal architecture for periods as long as after 3 years post flight.
 - Reference: Thomas Lang, Ph.D. University of California, San Francisco, CA
2. NASA research has shown that potassium citrate can be used in space as an effective countermeasure against renal stones, a major space flight risk.
 - Reference: Peggy Whitson, Ph.D., Johnson Space Center, Houston, TX
3. NASA research has developed a computer-based training method that teaches non-physicians to operate ultrasound as if they were technicians to enable telemedicine in rural or remote settings, like the ISS. Crewmembers on four International Space Station (ISS) missions have trained with the program and have performed ultrasound techniques while in space.
 - Reference: Scott A. Dulchavsky, M.D., Henry Ford Medical System, Detroit, MI
4. HRP research demonstrated that Vitamin D levels are quite low in crews during flight and that optimal levels of serum 25-hydroxyvitamin D [25(OH)D] for bone health can be maintained by taking at least 1,000 IU/day of Vitamin D supplements.
 - This work was prominently featured in the Institute of Medicine's recently released Calcium and Vitamin D report on dietary reference intakes
 - Reference: Scott M. Smith, Ph.D., Johnson Space Center, Houston, TX
5. HRP research found that that omega-3 fatty acids found in fish oil may play a role in mitigating bone breakdown that occurs during spaceflight and in osteoporosis. Astronauts who ate more fish lost less bone mineral after four-to-six-month spaceflights.
 - Reference: Scott M. Smith, Ph.D., Johnson Space Center, Houston, TX
6. HRP research analyzed astronaut journal entries that indicate conditions onboard the ISS are far better than tolerable, but short of what is necessary to support optimum human performance for sustained periods of routine operations.
 - Reference: Jack Stuster, PhD, CPE, Anacapa Sciences, Inc., Santa Barbara, CA

HRP Publications in High Impact Factor Journals

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2. Hagelstrom, R.T., et al., *Hyper telomere recombination accelerates replicative senescence and may promote premature aging*. Proc Natl Acad Sci U S A, 2010. 107(36): p. 15768-73.
3. Lam, Y.C., et al., *SNMIB/Apollo protects leading-strand telomeres against NHEJ-mediated repair*. EMBO J, 2010. 29(13): p. 2230-41.
4. Zhao, Y., et al., *Telomere extension occurs at most chromosome ends and is uncoupled from fill-in in human cancer cells*. Cell, 2009. 138(3): p. 463-75.
5. Dean, D.A., 2nd, D.B. Forger, and E.B. Klerman, *Taking the lag out of jet lag through model-based schedule design*. PLoS Comput Biol, 2009. 5(6): p. e1000418.
6. So, S., A.J. Davis, and D.J. Chen, *Autophosphorylation at serine 1981 stabilizes ATM at DNA damage sites*. J Cell Biol, 2009. 187(7): p. 977-90.
7. Mohawk, J.A., M.L. Baer, and M. Menaker, *The methamphetamine-sensitive circadian oscillator does not employ canonical clock genes*. Proc Natl Acad Sci U S A, 2009. 106(9): p. 3519-24.
8. Lieberman-Aiden E, van Berkum NL, Williams L, Imakaev M, Ragoczy T, Telling A, Amit I, Lajoie BR, Sabo PJ, Dorschner MO, Sandstrom R, Bernstein B, Bender MA, Groudine M, Gnirke A, Stamatoyannopoulos J, Mirny LA, Lander ES, Dekker J. *Comprehensive mapping of long-range interactions reveals folding principles of the human genome*. Science, 2009. 326(5950): 289-93.

HRP Cover Publications



Area: Space Radiation

March 2012: Research sponsored by HRP from a former National Space Biomedical Research Institute Postdoctoral Fellow was featured on the cover of the International Journal of Radiation Biology. The study provided evidence that exposure to radiation doses as low as 1 Gy can induce a significant increase in intestinal tumor multiplicity and enhance tumor progression in vivo.



Area: Nutrition

February 2011: Research sponsored by HRP and the National Science Foundation was featured on the cover of the Journal of Nutrition. The study provided evidence that in the absence of UV light, Vitamin-D supplementation can provide adequate levels of vitamin D and has the potential to mitigate immunosuppression in environments where stress hormones are elevated.



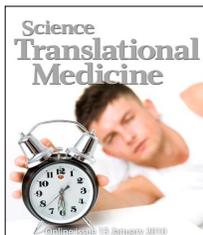
Area : Space Radiation

October 2010: Surprising finding that caspases (enzymes) previously associated with cell death regulation, play key roles in the reprogramming of human fibroblasts into induced pluripotent (capable of differentiating into different types of body cells) stem cells, potentially useful for human regenerative medicine.



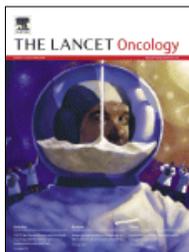
Area: Circadian Misalignment and Fatigue in Space

May 2010: Characteristics of Light Exposure Necessary for Development of Optimal Countermeasures to Facilitate Circadian Adaptation and Enhance Alertness and Cognitive Performance in Space



Area : Human Factors and Performance

Jan 2010: Uncovering Residual Effects of Chronic Sleep Loss on Human Performance. User-friendly software to predict individual human performance and alertness in space and on Earth



Area : Space Radiation

May 2006: Cancer risk from exposure to galactic cosmic rays: implications for space exploration by human beings

HRP Patents Filed (2009-2012)

Title	Contract
Artificial Intelligence Algorithm For Assessing Postural Stability During Normal Daily Activities Using Shoe Insert Pressure Sensors (Issued 9/6/11)	
Stroboscopic Image Modulation to Reduce the Visual Blur of an Object Being Viewed by an Observer Experiencing Vibration	
Chromatid Painting for Chromosomal Inversion Detection	NNX09CE42P
Use of Osteoclast Inhibiting Compounds to Prevent Radiation-induced Bone Loss	NNX07AB53H
Wearable Health Monitor	NNJ08JA57C
Beat-to-Beat Blood Pressure Monitor	NNX08CC15P
The Use of Low Shear Sedimental Environments to Modify Microbial Responses	NCC2-1362
Gene Expression Signatures for Colon Carcinogenesis and Radiation-Induced Cellular Transformation	NCC9-58
Electromagnetic Time-Variance Magnetic Fields (TVMF) to generate, and re-grow Cartilage Cells by a Noninvasive Method	NNX10CB13C
Rotary Exercise Equipment Apparatus and Method of Use Thereof	NNX10CB13C
Computer Controlled Exercise Equipment Apparatus and Method of Use Thereof	NNX10CB13C
Adaptive Exercise Profile Apparatus and Method of Use Thereof	NNX10CB13C
Variable Resistance Adaptive Exercise Apparatus and Method of Use Thereof	NNX10CB13C
Rapid Detection Of The Varicella Zoster Virus (VZV) In Saliva Samples	
Adaptive Exercise Equipment Apparatus and Method of Use Thereof	NNX10CB13C
Hands free TCD probe	NNJ06HI36C
Using Blood Clot in Microfluidic Valving Applications	NCC9-58
System for (semi) Continuously Fed Anaerobic Digestion of Solid and Soluble Organic Wastes, Bi-Products and Residues	NCC9-110
Self-enclosed and pipette free DNA/RNA Isolation device	

New Commercialized Products (2009-2012)

“SleepFit”- the PVT test and more – free download is available to NASA, and the public, on the Android phone (<http://www.apkbrain.com/apps/SleepFit---Alarm---Sleep-Log-165404.html>). Resulting from research on ISS (Reaction Self Test).

Schneider Trucking will use this new app to monitor fatigue in its long-haul truck drivers as part of a Department of Transportation program

New NASA/HRP-developed Technologies

- 2009: *Integrated Medical Model (IMM) v 2.0 for use in operations (JSC Exceptional Software Award)*
- 2009: *Portable Pulmonary Function System (PPFS) (collaboration with ESA)*
- 2009: *Lunar Electric Rover (LER) Ergometer*
- 2009: *Handheld Body Fluid Analysis System for Astronaut Health Monitoring*
- 2010: *In-situ-Intravenous Fluid Generation (IVGEN) technology*
- 2010: *Muscle Atrophy Research Exercise System (MARES) (collaboration with ESA)*
- 2010: *Treadmill Harness*
- 2010: *Onboard lighting requirements: ISS Solid State Light Assemblies (SSLAs)*
- 2010: *Mission Medical Information System (MMIS)*
- 2010: *Acute Radiation Risk and BRYNTRN Organ Dose (ARRBOD) software*
- 2010: *Scheduling and Planning Interface for Exploration (SPIFe) Tool*
- 2011: *Team Dimensional Training (TDT): a structured protocol for conducting post-performance team debriefings*
- 2011: *CogGauge - cognitive assessment tool to evaluate long-duration crew performance (SBIR)*
- 2011: *Advanced Diagnostic Ultrasound (ADUS) - Diagnostic guide to assist with remote ultrasound imaging*
- 2011: *Blood Counter In-A-Box*
- 2011: *Near-infrared spectroscopy (NIRS) Biosensor for Determination of Oxygen Utilization During Exercise*
- 2011: *Lunar Astronaut Spatial Orientation and Information System (LASOIS)*
- 2011: *Stress Management and Resilience Training for Optimal Performance (SMART-OP)*
- 2011: *Advanced Displays for Efficient Training and Operation of Robotic Systems*
- 2011: *rHEALTH Point-of-Care Lab Analysis Technology*
- 2011: *Near-Infrared Neuromonitoring (NIN) brain monitoring system*
- 2011: *SmartMed platform for medical/environmental data acquisition and management*
- 2011: *Lab-on-a-Chip point of care system*
- 2011: *Alternative Compression Garment (ACG)*
- 2011: *Relativistic Ion Track Structure Code (RITracks) - JSC Exceptional Software Award*
- 2011: *Galactic Cosmic Rays Event-based Risk Model (GERM) Code*
- 2012: *SleepFit - Psychomotor Vigilance Test (PVT)*
- 2012: *Behavioral Health and Performance Dashboard (SBIR)*
- 2012: *Accelerometric Daily Load Sensor*
- 2012: *On-Line Tool for the Assessment of Radiation in Space (OLTARIS)*
- 2012: *mini-Tissue Equivalent Proportional Counter (TEPEC)*

New NASA/HRP Technology Spin-offs

2009	<u><i>'Anti-Gravity' Treadmills Speed Rehabilitation</i></u>	ARC	<u><i>PDF</i></u>
2009	<u><i>Web-Based Programs Assess Cognitive Fitness</i></u>	JSC/ NSBRI	<u><i>PDF</i></u>
2009	<u><i>Image-Capture Devices Extend Medicine's Reach</i></u>	JSC	<u><i>PDF</i></u>
2009	<u><i>Medical Devices Assess, Treat Balance Disorders</i></u>	JSC	<u><i>PDF</i></u>
2009	<u><i>Electrolyte Concentrates Treat Dehydration</i></u>	ARC	<u><i>PDF</i></u>

Appendix C: Acronyms and Abbreviations

ACG	Alternative Compression Garment
ADUS	Advanced Diagnostic Ultrasound
ARED	Advanced Resistive Exercise Device
ARRBOD	Acute Radiation Risk and BRYNTRN Organ Dose
BHP	Behavioral Health and Performance Program Element
BMed	Behavioral Medicine
BOB	Bulk Overwrap Bag
CCISS	Cardiovascular and Cerebrovascular Control on Return from ISS
CM	Countermeasure
COLBERT	Combined Operational Load Bearing External Resistance Treadmill
Comm	Communication
CSA	Canadian Space Agency
CV	Cardiovascular
CEVIS	Cycle Ergometer with Vibration Isolation System
DEXA	Dual Energy X-ray Absorptiometry
ECP	Exercise Countermeasures Project
EMU	Extravehicular Mobility Unit
Environ	Environments
ESA	European Space Agency
ESPO	EVA Systems Project Office
EVA	Extra Vehicular Activity
Exer	Exercise
ExMC	Exploration Medical Capability Program Element
DCS	Decompression Sickness
FTT	Functional Task Test
FY	Fiscal Year
g	Gravity
GERM	Galactic Cosmic Rays Event-based Risk Model
Hab	Habitability
HHC	Human Health Countermeasures Program Element
HRP	Human Research Program
HSRB	Human System Risk Board
HW	Hardware
ICP	Intracranial Pressure
ICV	Integrated Cardiovascular
IHT	Intracranial Hypertension
Integr.	Integrated
IRP	Integrated Research Plan
ISS	International Space Station
IStar	International Space Station Testbed for Analog Research
IVD	Intervertebral Disc
IVGEN	Intravenous Fluid GENERation
JAXA	Japan Aerospace Exploration Agency
JSC	Johnson Space Center
LASOIS	Lunar Astronaut Spatial Orientation and Information System
LER	Lunar Electric Rover
MARES	Muscle Atrophy Research and Exercise System
Medops	Medical Operations
MLT	Muscle, Ligament, and Tendon
MMIS	Mission Medical Information System
MRI	Magnetic Resonance Imaging
MSTT	Medication/Symptom Tracking Tool
N ₂	Nitrogen gas

NEA	Near Earth Asteroid
NIN	Near-Infrared Neuromonitoring
NIRS	Near-infrared spectroscopy
NSBRI	National Space Biomedical Research Institute
NxPCM	Non-Exercise Physiology Countermeasures Project
O ₂	Oxygen
OCHMO	Office of the Chief Health and Medical Officer
OLTARIS	On-Line Tool for the Assessment of Radiation in Space
Ox.	oxidative
p/p	pre/post
PELs	Permissible Exposure Limits
PPFS	Portable Pulmonary Function System
PVT	Psychomotor Vigilance Task
RCAP	Research and Clinical Advisory Panel
Rev C	Document Revision C
RITracks	Relativistic Ion Track Structure Code
RSA	Russian Space Agency
SDTO	Station Development Test Objective
SHFH	Space Human Factors Engineering
SLAMMD	Space Linear Acceleration Mass Measurement Device
SM	Sensorimotor
SMART-OP	Stress Management and Resilience Training for Optimal Performance
SMO	Science Management Office
SPIFE	Scheduling and Planning Interface for Exploration
SSLAs	Solid State Light Assemblies
SSLM	Solid State Lighting Modules
STS	Space Transportation System
TCD	Transcranial Doppler
TDT	Team Dimensional Training
TEPEC	mini-Tissue Equivalent Proportional Counter
TVMF	Time-Variance Magnetic Fields
UMS	Urine Monitoring System
USP	United States Pharmacopeia
UV	Ultraviolet
VGE	venous gas emboli
VIIP	Visual Impairment/Intracranial Pressure
VO ₂ max	Maximum oxygen uptake
VZV	Varicella Zoster Virus
WMK	Water Microbiology Kit