

Advanced Capabilities Division  
International Space Station (ISS) Science Portfolio  
Determination and Management

# Advanced Capabilities Division

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## 1.0 Introduction

The International Space Station (ISS) program is a partnership that includes Canada, the member nations of the European Space Agency, Japan, Russia, and the United States to cooperate on the design, development, operation, and utilization of a permanently crewed, civil space station. ISS assembly began with the first element, which was launched in November 1998. The ISS has been permanently crewed since November 2000.

In a major space policy address on January 14, 2004, President Bush directed the National Aeronautics and Space Administration (NASA) to focus future human space exploration activities on returning humankind to the moon, as a prelude for human missions to Mars. The NASA Authorization Act of 2005 similarly called for research that would forward space exploration, as well as provide some provision for conducting non-exploration research. Included in this new, national vision of human space exploration are plans to complete the assembly of the ISS, retire the Space Shuttle fleet by the end of fiscal year (FY) 2010, and focus NASA's plans for utilization of the ISS to develop, demonstrate, and deliver technologies, biomedical countermeasures, and knowledge that will enable humans to withstand the rigors of space, and permit more ambitious, long-duration, exploration missions.

Along with concentrating NASA space systems development and operation efforts on space exploration, the U.S. research mission for the ISS was also re-evaluated and subsequently re-focused, primarily on mission-driven research. With the intent of mission-driven (exploration-oriented) research and the research mandated by the NASA Authorization Act of 2005 (non-exploration oriented), NASA continues to be the ISS "anchor tenant" of the ISS National Laboratory.

### 1.1 *Purpose and Scope*

The purpose of this document is to describe the history, policies, and processes used to determine the current science portfolio for ISS, and portfolio management by the Advanced Capabilities Division (ACD) of the Exploration Systems Mission Directorate (ESMD).

The ACD includes three independent programs: the Human Research Program (HRP), the Exploration Technology Development Program (ETDP), and the Lunar Precursor Robotic Program (LPRP). Of these programs, the HRP and ETDP include significant research elements, some strongly connected with ISS, while the LPRP mainly focuses on developing robotic missions to the moon.

The HRP is an applied research and technology program that addresses NASA needs for human health and performance risk mitigation strategies in support of the NASA's new focus on space exploration. HRP research and technology development is focused on the highest priority risks to crew health and safety with the goal of ensuring mission success and maintaining crew health.

Within the ETDP, the ISS exploration and non-exploration research projects provide guidance for fundamental (non-exploration) physical and life sciences, as well as applied physical sciences and technology demonstration research, with deliverables tied to Constellation program need dates.

The policies and processes referenced in this document apply to all ground and flight scientific research and development activities of the HRP and ETDP within ACD.

## 2.0 History

### 2.1 Introduction

Over the last decade, the plan for ISS utilization has changed several times as a result of budgetary constraints, recommendations from the National Academies, and directions from the executive and legislative branches of the U.S. Government. In order to effectively communicate the current ISS Utilization planning, and understand NASA's determination of its current portfolio, it is important to put into perspective the various studies that NASA had performed utilizing the services of the National Academies or specially-commissioned, blue-ribbon panels.

### 2.2 Recent ISS Relevant Studies by NASA Advisory Council Task Forces

In a 2001 report to the NASA Advisory Council (NAC), the International Space Station (ISS) Management and Cost Evaluation (IMCE) Task Force, chartered to evaluate ISS cost and management, called for prioritization of space station research to help determine its desired, final configuration. Two specific recommendations made related to ISS research priorities were as follows:

*The Task Force is unanimous in that the highest research priority should be solving problems associated with long-duration human spaceflight, including the engineering required for human support mechanism; and*

*Establish a research plan consistent with the priorities, including a prudent level of reserves, and compliant with the approved budget.*

The IMCE considered the research prioritization activity as a fundamental step toward maximizing the research benefits of the ISS.

To further define this recommendation of the IMCE task force's recommendation, the Research Maximization and Prioritization (REMAP) task force of the NAC was established in March 2002. The NAC chartered the REMAP task force to perform an independent external review and assessment of research productivity and priorities for the entire scientific, technological, and commercial portfolio of NASA's Office of Biological and Physical Research Enterprise (OBPR), and to provide recommendations on how to achieve the greatest progress in high-priority research within the President's budget request.

The REMAP task force identified and categorized OBPR research into two, broad categories (recognizing that some research would also overlap both goals):

- Research that emphasizes enabling human exploration of space
- Research that emphasizes intrinsic scientific importance or impact

Based on the OBPR portfolio at that time, the REMAP task force categorized the research areas as depicted in Figure 1. The ISS was the research platform for all of these areas.

For example, in future human space exploration, advanced life support systems need to be developed to increase the resource recovery from gaseous, aqueous, and solid wastes, in

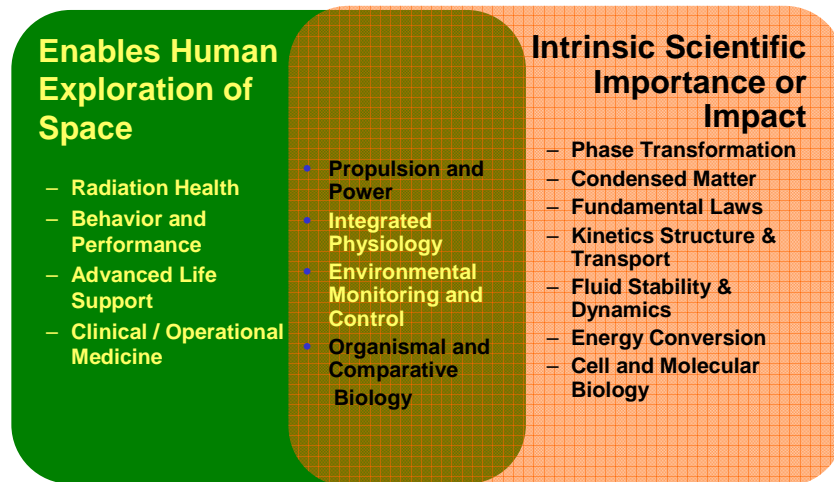
order to reduce the need for resupply from Earth. The ISS serves as a platform to gain operational experience on this advanced life support system.

In addition, because long-duration stays of six months are analogous to a Mars transit mission, the ISS was also deemed as a pertinent, research environment for clinical and operational medicine, as well as for behavioral and performance evaluation.

In the area of cellular and molecular biology, the long-duration microgravity environment that the ISS provides is aptly suited for performing research on multiple generations of cell growth. Finally, in the physical sciences, the availability of the ISS as a long-duration microgravity environment has enabled key findings in areas such as colloidal fluids and phase separations.

**Finding: Categorization of Highest Priority Research**

**ReMaP - 2002**



**Figure 1 - REMAP Research Area Prioritization**

**2.3 Recent Studies of ISS Research Priorities by National Academy of Sciences and Blue-Ribbon Panels**

Four other relevant studies of the National Academies, two from the Space Studies Board (Assessment of Directions in Microgravity and Physical Sciences, NRC [2003] and Microgravity Research in Support of Technologies for the Human Exploration and Development of Space and Planetary Bodies [2000]) and two from the Institute of Medicine (Safe Passage: Astronaut Care for Exploration Missions [2001] , and A Risk Reduction Strategy for Human Exploration of Space: A Review of NASA's Bioastronautics Roadmap [2006]). Safe Passage: Astronaut Care for Exploration Missions report makes a number of recommendations concerning NASA's structure for clinical and behavioral research.

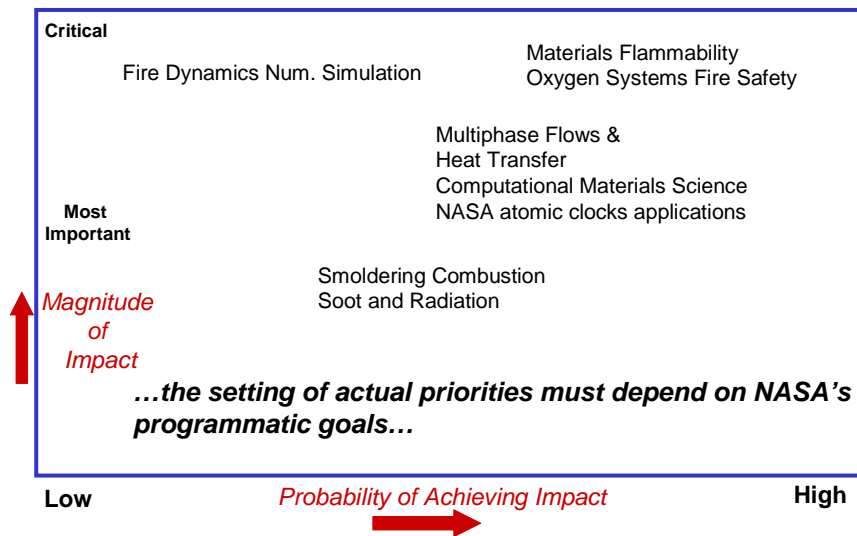
All four studies looked at the high-priority, research areas within each of the microgravity disciplines or made a number of recommendations concerning NASA's structure for clinical and behavioral research. Figure 2 represents the areas that were categorized in terms of the

magnitude of their impact, and the probability of achieving the stated impact on NASA’s technology needs for exploration missions.

The intent of this categorization was to provide NASA with the tools to rationally select the best research. Both the REMAP task force and the NRC report stated that this prioritization provided guidance to NASA, and that the actual research portfolio would be determined based on programmatic decisions made by NASA.

**High Priority Physical Science Research for NASA  
Technology Needs**

“Assessment of Directions in Microgravity and Physical Sciences Research at NASA” **NRC/SSB Report 2003**



**Figure 2 - Research Area Categorization for Exploration**

In concert with the guidance provided by the IMCE, REMAP, and the aforementioned NRC reports, NASA’s OBPR developed Strategic Research Plans that were laid out in the form of organizing questions. These plans were primarily developed by holding strategy workshops, using input from the external community. The plans were further vetted by the Biological and Physical Research Advisory Committee and the Space Station Utilization Advisory Subcommittee. Both of these committees were impressed with these plans, and formally commended them as “*well conceived, organized, and connected document from end... and is certainly linked to REMAP, the Young report (IMCE) and connected to exploration as well as forward thinking.*”

In the Life Sciences area, the Institute of Medicine Report “Safe Passage” (National Academy Press, 2001) identified two exploration research themes requiring spaceflight experiments especially in the context of the ISS:

- (1) *Not enough is known about risks to human health and how to manage/mitigate them during long-duration missions beyond Earth orbit and*
- (2) *Everything reasonable should be done to gain necessary understanding before humans are sent on space exploration missions (Safe Passage, Page 3).*

This led to their recommendation that NASA develop a research plan designed to increase biomedical knowledge about physiological and psychological adaptations to long-duration space travel, including pathophysiological "... changes associated with environmental forces and disease processes in space; prediction, development, and validation of preventive, diagnostic, therapeutic, and rehabilitative measures for pathophysiological changes, including those that are associated with aging; and the care of astronauts during space missions." The report recommended that NASA's strategic research plan should be systematic, prospective, comprehensive, periodically reviewed and revised, and transparent to the astronauts, the research community, and the public, and should be focused on:

- providing an understanding of basic pathophysiological mechanisms by a systems approach;
- **using the International Space Station as the primary test bed for fundamental and human-based biological and behavioral research;**
- using more extensively analog environments that already exist and that have yet to be developed;
- using the research strengths of the federal government, universities, and industry, including pharmaceutical, bioengineering, medical device, and biotechnology firms; and
- developing the health care system for astronauts as a research database.

The Space Studies Board (SSB) of the NRC (National Academy of Sciences Press, 2006) reviewed NASA's plans for the ISS, and recommended that the mission objectives for the ISS in support of extended crewed exploration of space should include:

- Developing and testing technologies for exploration spacecraft systems
- Developing techniques to maintain crew health and performance on missions beyond low Earth orbit
- Gaining operational experience that can be applied to exploration missions

The panel agreed that these are appropriate and necessary roles for the ISS, although the SSB expressed concerns about areas omitted from this list. The panel concluded that the ISS provides an essential platform for research and technology testing in support of long-term human exploration, including lunar outpost missions and, most especially, the human exploration of Mars.

The NRC identified the following research areas as of high priority within the context of ISS:

- Effects of radiation on biological systems
- Loss of bone and muscle mass during spaceflight
- Psychosocial and behavioral risks of long-term space missions
- Individual variability in mitigating a medical/biological risk
- Fire safety aboard spacecraft
- Multiphase flow and heat transfer issues in space technology operations



## **2.4 NASA Internal Analyses for ISS Utilization for Implementing the Vision for Space Exploration**

The tragic loss of the Space Shuttle Columbia in Feb 2003 forced NASA to re-evaluate its research priorities, as it was not feasible for NASA to provide all of the logistics and the experimental facilities to the ISS as originally envisioned. During the period the Shuttle was grounded, all of the Agency's upmass, down mass, and crew transportation was provided through the Russian Soyuz and Progress spacecrafts.

NASA's new vision and focus on space exploration was announced in 2004, and OBPR vectored its research efforts on ISS for the following purposes:

- Research, development, test, and evaluation of biomedical protocols for human health and performance on long-duration space missions;
- Research, development, test, and evaluation of systems readiness for long-duration space missions; and
- Development, demonstration, and validation of operational practices and procedures for long-duration space missions

To further align its portfolio with the new goals and objectives, ESMD conducted an internal Zero-Based Review (ZBR) of all the heritage OBPR programs in 2005. The intent of this review was to identify gaps, prioritize needs, and make recommendations about the highest priority research within the new budgetary constraints, while phasing out lower-priority research that was not aligned to the new focus on human space exploration. This review considered recommendations from previous review panels of the National Academies, and from the NASA-convened Research Maximization and Prioritization (REMAP) task force.

The ZBR process and subsequent results were reviewed by non-advocate panels involving internal and external experts. An independent prioritization of ISS exploration research activities was also carried out using a Strategy to Task to Technology (STT) process. As a result of the ZBR process, the following areas were identified as of the highest priority:

- Space radiation health and shielding
- Advanced environment control and monitoring
- Advanced extravehicular activity (EVA) suits
- Human health and countermeasures
- Advanced life support
- Exploration medical care
- Space human factors and behavioral health

In late 2005, the entire Human Systems Research and Technology (HSRT) portfolio was further focused, and budget reduced by the NASA Exploration Systems Architecture Study team (ESAS). This resulted in elimination of some ISS research activities (sortie missions for animal research, space atomic clock, some two-phase flow). However, the ESAS also recognized that the ISS is the only spacecraft available for studying the effects of long-duration microgravity on human health. Understanding that it will take six to nine months of

microgravity spaceflight in each direction to reach Mars, and because the ISS will only be available for about ten years, it is prudent to continue this facility for high-priority, human health research.

## **2.5 Congressional Direction on Fundamental Sciences Research**

Concerned that NASA was focusing and re-vectoring all the ISS-related tasks to solely exploration-based activities, the NASA Authorization Act of 2005 directed NASA to:

*“...allocate at least 15 percent of the funds budgeted for ISS research to ground-based, free-flyer, and ISS life and microgravity science research that is not directly related to supporting the human exploration program...”*

*and*

*“...carry out to the maximum extent practicable, basic, applied, and commercial ISS research in fields such as molecular crystal growth, animal research, basic fluid physics, combustion research, cellular biotechnology, low-temperature physics, and cellular research...”*

The intent of this allocation was to sustain, to the maximum extent practicable, the existing U.S. scientific expertise and research capability in microgravity research.

## **3.0 Formation of ISS Utilization Rationale After the NASA 2005 Authorization Act, and Using the Advice of External Groups**

NASA used the new vision for space exploration as announced in 2004, in concert with the aforementioned NRC reports and NASA studies, to develop the current ISS Utilization planning for Human and Physical Sciences Research. During this formulation activity, an assessment of the resource envelope, upmass and downmass capability, international partner commitments and leveraging off their capabilities, the available facilities on the space station, and maturity of the experimental payloads were all taken into consideration.

Table 1 makes an attempt to summarize the research areas that the NRC, through various studies, deemed important (as cited in the preceding section), as well as NASA’s plans to conduct experiments in those areas. The common underlying theme that can be deduced from Table 1 is that all of the panels came to a similar conclusion on the research portfolio’s composition for a particular, intended use of the ISS.

The Agency’s planning takes into account using the ISS to the maximum extent possible, given the constraints that it faces today. NASA also fully intends to continue making efficient use of ISS resources through cooperative research with ISS Partners. NASA has been actively working with the European Space Agency (ESA), Russian Federal Space Agency (Roscosmos), Canadian Space Agency (CSA), and the Japan Aerospace Exploration Agency (JAXA) to ensure that research is coordinated to reduce overlap, take advantage of efficient research combinations, and optimize the use of all research and hardware capability. NASA actively planned ISS usage in partnership with the member nations, and has agreements in place to share data, and in some cases experimental samples for optimal gain from any experiment performed.

**Table 1 – ACD ISS Payloads Plan from 2006-2016 (Refer to Appendix B for Acronyms)**

**Exploration Research**

Research Area	Committee	ISS Experiments/Payloads										
		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Fire Safety	NRC 2000, 2003, 2006, REMAP	DAFT	SAME	MDCA & FLEX					FLAME			
Multiphase flow and heat transfer (power, propulsion and life support)	NRC 2000, 2003 2006	CFE			LMM & CVB, BXF	CCF	ZBOT-1			ZBOT-2, SEP		ZBOT-3
Technology Demonstrations	NRC 2006, REMAP	LOCAD PTS		E Nose	VCAM,	CSPE						

Key

- Completed Experiments
- Planned research to characterize physiologic response or test technology
- Possible required follow-on research - countermeasure validation

Risk of inability to adequately treat an ill or injured crew member	REMAP, Safe Passage, NRC 2006		Braslet-M DTO				Med-Water					
Risk of inadequate nutrition	REMAP, Safe Passage, NRC 2006	Nutrition									Validate-Nutrition CM	
Risk of inadequate food system	REMAP, Safe Passage, NRC 2006	Stability- Food Nutrients					Sensory Qualities					
Risk of behavioral and psychiatric conditions	REMAP, Safe Passage, NRC 2006	Journals					Tool Validation					
Risk of radiation carcinogenesis from space radiation	REMAP, Safe Passage, NRC 2006	Ongoing ISS data collection Through Medical Data To update Risk Models										
Risk of compromised Extravehicular Activity (EVA) performance and crew health due to inadequate EVA suit systems	REMAP, Safe Passage, NRC 2006	Ongoing ISS data collection From EVAs to Update Risk Models and Inform Design										
Risk of accelerated osteoporosis	REMAP, Safe Passage, NRC 2006	Bisphosphonates SMO										
		Bone Recovery										
		Bone Turnover										
		Bone Quality										

**Table 1 – ACD ISS Payloads Plan from 2006-2016 (Refer to Appendix B for Acronyms)**  
**Exploration Research**

Research Area	Committee	ISS Experiments/Payloads										
		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
								Calcium Isotope				
						Vibe Flight Validation			Bone CM Validation			
Risk of orthostatic intolerance during re-exposure to gravity	REMAP, Safe Passage, NRC 2006		Midodrine-SDBI						Hypovolemia CM Validation			
Risk of impaired performance due to reduced muscle mass, strength and endurance	REMAP, Safe Passage, NRC 2006	Foot		Functional Task Test								
				Harness SDTO	ARED Muscle Study							
									Exercise Prescription Optimization Validation			
Risk of reduced physical performance capabilities due to reduced aerobic capacity	REMAP, Safe Passage, NRC 2006	PFE-OUM		VO2 Max				Exercise Prescription Optimization Validation				
Risk of therapeutic failure due to ineffectiveness of medication	REMAP, Safe Passage, NRC 2006	Stability- Pharmaceuticals		In Flight PK-PD					CM Validation			
		PMZ										
Risk of performance errors due to poor team cohesion, performance, & psychosocial adaptation; inadequate selection/team composition & training	REMAP, Safe Passage, NRC 2006				Voice Acoustic and Facial Cue Recognition							
							Conflict Mgmt; Crew Communication Tools					
								Autonomy Studies				
								Training Tools		Team Cohesion CM Tool Validation		
Risk of cardiac rhythm problems	REMAP, Safe Passage, NRC 2006			Integrated Cardiovascular; Nutrition Effects on Cardiac Rhythm Problems						Validate CM		
Risk of intervertebral disc damage	REMAP, Safe Passage, NRC 2006			Post-Flight MRIs				Validate Disc Damage CMs				
Risk of crew adverse health event due to altered immune response	REMAP, Safe Passage, NRC 2006	SWAB										
			Integrated Immune-SDBI							Validate CM		
		Epstein-Barr										
Risk of impaired ability to maintain control of vehicles and other complex systems	REMAP, Safe Passage, NRC 2006	Mobility Pre/Post			Manual Visual Control				Validate CM			

**Table 1 – ACD ISS Payloads Plan from 2006-2016 (Refer to Appendix B for Acronyms)**  
**Exploration Research**

Research Area	Committee	ISS Experiments/Payloads										
		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Risk of performance errors due to sleep loss, circadian desynchronization, fatigue, and work overload	REMAP, Safe Passage, NRC 2006	Sleep Actigraph				Fatigue Meter Development Test					Validate CMs	
					Psychomotor Vigilance Test							
					Acoustic Impact							
					Sleep-Wake Medications							
					Optimal Work-Rest Schedule Validation							
Risk of operational impact of prolonged daily required exercise	REMAP, Safe Passage, NRC 2006			VO2 Max (Same as in Reduced Aerobic Capacity)				CM Validation and Prescription Optimization				
				ISS Muscle Studies								
Risk of unnecessary operational limitations due to inaccurate assessment of cardiovascular performance	REMAP, Safe Passage, NRC 2006			VO <sub>2</sub> Max (Same as in Reduced Aerobic Capacity)								
Risk of Bone Fracture	REMAP, Safe Passage, NRC 2006	Bisphosphonates SMO										
						Bone Turnover						
						Bone Quality						
						Calcium Isotope						
						Vibe Flight Validation				Bone CM Validation		
Risk of renal stone formation	REMAP, Safe Passage, NRC 2006	Renal Stone						Renal Stone CM Validation				
Risk of urinary tract dysfunction	REMAP, Safe Passage, NRC 2006							CM Validation				
Risk of impaired vision due to refractive visual changes during long duration spaceflight	REMAP, Safe Passage, NRC 2006			Vision Changes				CM Validation				
Risk of adverse health effects due to exposure to hypoxic environments	REMAP, Safe Passage, NRC 2006							CM Validation				
Risk of adverse health effects due to prolonged exposure to elevated carbon dioxide levels	REMAP, Safe Passage, NRC 2006							CM Validation				

Non-Exploration Research												
Research Area	Committee	ISS Experiments/Payloads										
		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
<i>Physical Science ISS/Shuttle</i>												
Fluids	REMAP, NRC 2006, 2005 Authorization Act		InSPACE-2	BCAT-4, SHERE			OASIS		Colloids			
Combustion	REMAP, NRC 2006, 2005 Authorization Act				SPICE		FLEX-2		ACME			
Materials	REMAP, 2005 Authorization Act		CSLM-2					DSIP	GTS	QUASI		
<i>Physical Science Free-Flyers</i>												
Fluids (Free-Flyer)	2005 Authorization Act		GRADFLEX									
<i>Life Science ISS/Shuttle</i>												
Microbial and Cellular	REMAP, 2005 Authorization Act	POEMS, Microbe, Leukin	SPEGIS, PKINASE	PADIAC								
Animal (nonrodent)	REMAP, 2005 Authorization Act	FIT										
Plants	2005 Authorization Act	EMCS-Tropi			APEX-Cambium							
<i>Life Science Free-Flyers</i>												
Microbial and Cellular	REMAP, 2005 Authorization Act	GeneSat-1	Foton M3	PharmaSat-1, MoOSat-1	MoOSat-2	MicroSat-2, MicroSat-3	MoOSat-3		MoOSat-4			
Animal (nonrodent & rodent)	2005 Authorization Act		Foton M3			Bion M1		MicroSat-4	MoOSat-5, Bion M2	MicroSat-5	MoOSat-6	MicroSat-6, Bion M3

Microgravity Research in Support of Technologies for the Human Exploration and Development of Space and Planetary Bodies (2000)  
Report by the NASA Biological and Physical Research Maximization And Prioritization (REMAP) Task Force to the NASA Advisory Council (2002)  
Assessment of Directions in Microgravity and Physical Sciences Research at NASA (2003)  
Review of NASA Plans for the International Space Station (2006)  
NASA's Exploration Systems Architecture Study -- Final Report (2005)

### **3.1 Human Research Program Exploration Research**

The goal of Human Research Program (HRP) exploration research is to provide human health and performance countermeasures, knowledge, technologies, and tools to enable safe, reliable, and productive human space exploration. To meet this goal, HRP has analyzed the value and necessity of ISS to investigate and quantify human health and performance risks to exploration mission crews. Based on a set of risks, the Human Research Program has defined a research and technology plan to address them. Between now and 2016, HRP will use ISS to:

- Perform research needed to identify, quantify and mitigate risks to human health and performance
- Identify and flight validate potential mitigating countermeasures

This plan, focused on exploration missions to the moon and Mars, includes spaceflight (Space Shuttle and ISS) and ground experiments and facilities. The previously published analysis of risks cataloged in the Bioastronautics Roadmap was used to determine next steps in research and technology necessary to reduce these risks to acceptable levels. The complete list of risks to be addressed on the ISS is provided in Table 2.

ISS is a critical platform to acquire knowledge, test countermeasures, and evaluate the technologies necessary for developing and validating risk mitigation techniques for human exploration missions. ISS research is essential for two reasons. Firstly, there is no effective ground-based analog to conduct the work on Earth; secondly, research activity needs the complete operational environment of spaceflight to validate the countermeasure or technology.

Of the 32 risks within the HRP, 17 risks were originally identified as needing ISS resources, with another six risks under review. As the HRP continued program formulation and risk review, the ISS was deemed necessary for the six risks that were under review:

- 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 impaired vision due to refractive visual changes during long-duration spaceflight
- 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

Furthermore, two HRP risks are associated with current ISS operational activities: 1) Risk of radiation carcinogenesis from space radiation, and 2) Risk of compromised extravehicular activity (EVA) performance and crew health due to inadequate EVA suit systems.

Data from regular, ongoing ISS operations was identified to expand the HRP risk evidence base, and data analysis may identify a need for future experiments. Therefore, these two risks are included in the HRP ISS utilization plan.

At this time within the HRP, the ISS environment is necessary to mitigate 25 of the 32 human health risks anticipated on exploration missions. Only those risks that require ISS are described in this document.

The 25 HRP risks and the associated experiments can be categorized based on their mapping to five organizational HRP elements:

- 1) **Space Radiation:** The Space Radiation Element works to ensure that the crews can safely live and work in the space radiation environment without exceeding the acceptable risk limits during and after the missions. The element develops scientifically-based, integrated approaches to understanding, projecting, and mitigating the lifetime risks associated with radiation exposure to astronauts.
- 2) **Human Health Countermeasures:** The focus of the Human Health Countermeasures Element is to develop and validate an integrated suite of countermeasures for exploration missions. This diverse element comprises six projects that address exercise, non-exercise, and EVA countermeasures, as well as flight analog facilities to test potential countermeasures before their actual flight verification.
- 3) **Exploration Medical Capability:** The Exploration Medical Capability Element defines requirements for crew health maintenance during exploration missions. The Exploration Program presents significant, new challenges to crew health, ranging from treatment to health management.
- 4) **Behavioral Health and Performance:** The goals of the Behavioral Health and Performance Element are to identify and characterize the behavioral health and performance risks associated with training, living, and working in space, and upon returning to Earth. The element develops strategies, tools, and technologies to mitigate these risks, and prevent performance degradation and human errors.
- 5) **Space Human Factors and Habitability:** The purpose of the Space Human Factors and Habitability Element is to develop products and deliverables to ensure successful human systems engineering, human factors engineering, environmental health, and food technology.



*Table 2 - Human Health and Performance Risks that Require ISS as a Research Platform for Resolution*

Risk of inability to adequately treat an ill or injured crew member
Risk of inadequate nutrition
Risk of inadequate food system
Risk of behavioral and psychiatric conditions
Risk of radiation carcinogenesis from space radiation
Risk of compromised extravehicular activity (EVA) performance and crew health due to inadequate EVA suit systems
Risk of accelerated osteoporosis
Risk of orthostatic intolerance during re-exposure to gravity
Risk of impaired performance due to reduced muscle mass, strength and endurance
Risk of reduced physical performance capabilities due to reduced aerobic capacity
Risk of therapeutic failure due to ineffectiveness of medication
Risk of performance errors due to poor team cohesion, performance, and psychosocial adaptation; inadequate selection/team composition and training
Risk of cardiac rhythm problems
Risk of intervertebral disc damage
Risk of crew adverse health event due to altered immune response
Risk of impaired ability to maintain control of vehicles and other complex systems
Risk of performance errors due to sleep loss, circadian desynchronization, fatigue, and work overload
Risk of operational impact of prolonged daily required exercise
Risk of unnecessary operational limitations due to inaccurate assessment of cardiovascular performance
Risk of bone fracture
Risk of renal stone formation
Risk of urinary tract dysfunction
Risk of impaired vision due to refractive visual changes during long duration spaceflight
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

The following sections describe examples of ISS research required to mitigate risks in each of those five areas.

### 3.1.1 Space Radiation

***Risk of radiation carcinogenesis from space radiation:*** Space radiation exposure increases cancer morbidity and mortality risk in astronauts, and may be influenced by other spaceflight factors, including microgravity and environmental contaminants. Current space radiation risks estimates are based on human epidemiology data for X-rays 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, as 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 countermeasures approaches to be evaluated and improved or unless mission durations are constrained.

ISS data collected during nominal operations is 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. Currently, each ISS crewmember's medical history is followed, and these data are used to update risk models.

### 3.1.2 Human Health Countermeasures

***Risk of inadequate nutrition:*** The risks to adequate nutrition include misjudging nutritional needs; the instability of nutrients during long-duration flight; inadequate fluids, macronutrients, micronutrients, vitamins, and other elements in the diet; and spaceflight-induced changes in food absorption.

ISS experiments will be 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 Nutritional Status Assessment Study, currently being conducted on the ISS, will increase our understanding of the nutritional status and nutrient requirements for astronauts. Flight validation of nutritional requirements will occur in 2015-2018, and updates to the nutrition standard will be made in 2018.

***Risk of compromised EVA performance and crew health due to inadequate EVA suit systems:*** Improperly designed extravehicular activity (EVA) suits can result in the inability of the crew to perform as expected, and can cause biomechanical (torn rotator cuff, for example) or decompression injury. Suit developers must fully understand the impact of the suit design on crew performance and health to ensure proper design of parameters, such as mobility, pressures, nutrition, and life support.

Data from ISS-based EVAs will be used to identify suit-induced trauma, and 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 help optimize future suit designs and determine metabolic profiles.

**Risk of adverse health effects due to exposure to hypoxic environments:** Spacecraft designers strive to maintain a normal terrestrial atmosphere for crewmembers; however, frequent EVAs necessitate decreasing the atmospheric nitrogen levels to decrease the risk of decompression sickness. Decreasing nitrogen partial pressure without decreasing oxygen partial pressure creates a significant fire risk. Concerns exist whether crew performance could be adversely affected if cabin oxygen pressures are decreased with cabin nitrogen to reduce the risk of fire.

The ISS will be used to develop and flight-validate countermeasures if data mining activities show that there are known issues associated with hypoxic environments.

**Risk of adverse health effects due to prolonged exposure to elevated carbon dioxide levels:** Available scrubbing technologies cannot lower cabin carbon dioxide (CO<sub>2</sub>) levels to terrestrial atmospheric concentrations. In addition, frequent repairs of complex scrubbing equipment have led to elevated CO<sub>2</sub> levels on multiple occasions.

It is unclear how chronic exposure to elevated ISS CO<sub>2</sub> levels affects human health. Normal levels of CO<sub>2</sub> onboard the ISS are at 5mm mercury. When the CO<sub>2</sub> levels rise above 5mm of mercury, the crew complains of symptoms (i.e., headaches, malaise, and general poor health). Most of the data associated with this risk is anecdotal.

The ISS will be used to determine whether the CO<sub>2</sub> levels are chronically just below the symptom levels (5 mm mercury), and if so, the subsequent effect on the body. If issues exist, the ISS will be used to flight-validate countermeasures to elevated CO<sub>2</sub> levels.

**Risk of accelerated osteoporosis:** During spaceflight, humans lose bone mineral density primarily due to the lack of gravitational stimulus to the skeletal system. It is unclear whether bone mineral density loss of 1% per month that occurs in microgravity will stabilize at a lower level, or continue to diminish with longer space missions. Greater understanding of mechanisms of bone demineralization in microgravity (leading to post-mission osteoporosis) is necessary to frame this risk, as well as to understand how current and future osteoporosis treatments may be employed.

ISS research will provide “space-normal” data to define in-flight and post-flight bone density trends, and also help define long-term recovery of bone mineral density. This would enable the HRP to deliver a bone recovery countermeasure to mission operations in 2020 to mitigate a risk for long-duration lunar and Mars missions. Flight studies using the ISS to analyze bone turnover will be performed in 2011-2014 to validate the methodology and novel technologies in a spaceflight environment.

ISS studies will document the return to normal bone remodeling post-flight in crewmembers that took pharmaceutical countermeasures, and will be used to validate nutritional countermeasures during long-duration spaceflight in the 2013-2016 timeframe for delivery to mission operations by 2016. A current ISS study will determine whether bisphosphonates or other pharmaceuticals, in conjunction with the routine in-flight exercise program, will protect ISS crewmembers from the regional decreases in bone mineral density documented on previous ISS missions.

**Risk of bone fracture:** It is unclear whether the 1% per month bone mineral density in microgravity will plateau or continue, or whether the fractional gravity of the moon or Mars would mitigate the loss during long space missions. This level of bone loss does not create

an unacceptable risk of fractures for ISS missions, but in longer missions, or missions with a fractional gravity component, it could create unacceptable 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.

Validated technologies to monitor changes in bone quality for use in spaceflight applications will be delivered. After initial ground-based studies, follow-on ISS studies will be used to flight-validate the technology. A flight study will be conducted to assess spine health before and after ISS missions. The initial measures will determine whether there are vertebral compression fractures in returning crew.

***Risk of impaired performance due to reduced muscle mass, strength and endurance:***

There is a growing research database which suggests that skeletal muscles, particularly postural muscles of the lower limb, undergo atrophy and structural and metabolic alterations during spaceflight. However, the relationships between in-flight exercise, muscle changes, and performance levels are not well understood.

ISS will be required to validate optimized countermeasures and hardware (e.g., resistance exercise device, treadmill, cycle ergometer) for muscle atrophy and structural and metabolic alterations during spaceflight. The ISS will be used to validate the functional task tests that measure physiological decrements in crewmembers.

***Risk of renal stone formation:*** Alterations in hydration state (relative dehydration) and bone metabolism (increased calcium excretion) during exposure to microgravity may increase the risk of kidney stone formation.

ISS investigations will develop an understanding of the stone-forming risk that crewmembers experience during and after spaceflight, and analyze the ISS test data to determine the efficacy of potassium citrate as a countermeasure to reduce this risk. 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 long-duration lunar outpost and Mars transit analog for countermeasure validation if countermeasures other than potassium citrate are needed.

***Risk of operational impact of prolonged daily required exercise:*** Muscle atrophies in microgravity, and strength decreases as well. Currently, significant, daily time is devoted to crew exercise during spaceflight. Making exercise more efficient may allow similar beneficial effects to be achieved more simply, and in shorter time, which would provide more crew time for operational support.

The ISS is needed to benchmark crew strength requirements, and test exercise equipment and regimens against these benchmarks. This will promote the development of more efficient, yet equally safe, exercise regimens. The ISS is required to validate instrumentation (advanced resistive exercise device), optimized countermeasures (VO<sub>2</sub> max), and exercise devices for exploration.

***Risk of therapeutic failure due to ineffectiveness of medication:*** Based on subjective reports, drugs are effective during spaceflight. However, post-flight analyses of pharmaceuticals exposed to long durations in the ISS environment and returned to Earth have shown significant decreases in efficiency. Risk is related to record keeping of medication

use, efficacy, and side effects. Additional risk results if medications are found to be ineffective, or if spaceflight affects drug stability.

The ISS will be used to perform drug efficacy studies (e.g., effects of space environment like radiation on drug stability). The current “Antimicrobial Medication Stability During Spaceflight (Stability)” study looks at the effects of radiation in space on complex, organic molecules in medicine. This experiment could help researchers develop more stable and reliable pharmaceuticals suitable for future long-duration missions to the moon and Mars.

Another study, “Bioavailability and Performance Effects of Promethazine during Spaceflight”, will examine the performance-impacting side effects of promethazine and its bioavailability, which is the degree to which a drug can be absorbed and used by the parts of the body on which it is intended to have an effect.

***Risk of orthostatic intolerance during re-exposure to gravity:*** Post-flight orthostatic intolerance, the inability to maintain blood pressure while in an upright position, is an established, space-related medical problem. Currently, anti-“g” suits have been used to mechanically (by use of pressure on the lower extremities) maintain blood pressure for astronauts returning from spaceflight.

The ISS is being used currently to test the pharmaceutical Midodrine as a countermeasure against post-flight orthostatic hypotension. If successful, it will be available as an additional countermeasure to the dizziness caused by the blood-pressure decrease that many astronauts experience upon returning to the Earth's gravity.

***Risk of reduced physical performance capabilities due to reduced aerobic capacity:*** Astronauts' physical performance during a mission, including activity during spacewalks in micro- and fractional gravity, is critical to mission success. Reduced aerobic capacity, in addition to decreased skeletal muscle strength and endurance, may put mission success at risk.

The ISS will be used to measure aerobic capacity and cardiac output during and after long-term spaceflight. In addition, ISS will be used to optimize and validate prescriptions for exercise volumes, regimens, and equipment. ISS will be used to optimize and validate lunar tasks and their physical performance costs. The current “Periodic Fitness Evaluation/Oxygen Uptake Measurement (PFE-OUM)” experiment will be used to determine the crewmember's aerobic capacity during spaceflight.

***Risk of unnecessary operational limitations due to inaccurate assessment of cardiovascular performance:*** Current in-flight indicators of cardiac performance may not accurately reflect astronauts' true cardiovascular performance. Making operational decisions, such as suitability for spacewalks, based on inaccurate cardiac performance measures may unnecessarily restrict crewmembers for critical activities or, more seriously, could subject crewmembers to activities for which they are not physically prepared. Accurate measurement of crewmember aerobic capacity can eliminate this risk.

The ISS is required for initial work and countermeasure validation for a number of cardiovascular studies. For example, studies will address a countermeasure to protect cardiac function, and to measure aerobic capacity and cardiac output. If an issue is discovered, the ISS will be used to develop the appropriate countermeasures.

**Risk of cardiac rhythm problems:** 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.

Scientists will use the ISS environment 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.

In addition, the ISS environment may be required to validate countermeasures if arrhythmias are observed. The current experiment, “Integrated Cardiovascular”, will quantify the extent and time course of cardiac atrophy and identify its mechanisms. The functional consequences of this atrophy also will be determined for cardiac filling dynamics, orthostatic tolerance, and arrhythmia susceptibility both in space on the ISS, and following return to Earth.

**Risk of intervertebral disc damage:** Studies have shown that astronauts have a higher incidence of intervertebral disc damage than the general population due to change in the spine (primarily elongation) due to microgravity. Astronauts generally report periods of back pain during the early days of a spaceflight. Extended exposures to microgravity (and possibly fractional gravity) may lead to an increased risk of spinal nerve compression and back pain.

Additional evidence will be gathered from ISS crewmembers to establish whether the lengthening of the spine exacerbates the risk for intervertebral damage with loading. ISS studies will determine the extent of this problem, and guide design of re-entry and post-flight protocols, as well as future re-entry spacecraft.

**Risk of crew adverse health event due to altered immune response:** Studies have shown that human immune function is altered in- and post-flight. Despite this finding, it is unclear whether this change leads to an increased susceptibility to disease.

The ISS is required to develop and validate an immune monitoring strategy consistent with operational flight requirements and constraints. There are no procedures currently in place to monitor immune function or its effect on crew health, although immune dysregulation has been demonstrated during spaceflight. The ISS will be used to validate potential countermeasures, if an issue is found.

Current research, “Validation of Procedures for Monitoring Crew Member Immune Function”, is being used to assess the clinical risks resulting from effects of spaceflight on the human immune system, and will validate a flight-compatible immune monitoring strategy. “Spaceflight-Induced Reactivation of Latent Epstein-Barr Virus” will provide insight for possible countermeasures to prevent the potential development of infectious illness in crewmembers during spaceflight.

**Risk of urinary tract dysfunction:** Multiple cases of urinary retention and subsequent urinary tract infections have been observed during short-duration spaceflight, chiefly among female astronauts. It is not clear why exposure to microgravity adversely affects the functioning of the urinary tract, nor is the clinical management of these cases in microgravity understood.

NASA will perform data mining on ISS subjects to determine known issues associated with urinary tract infections. If issues exist, countermeasures will be developed, and flight validation studies conducted on ISS.

***Risk of impaired vision due to refractive visual changes during long-duration spaceflight:*** Significant changes in visual refraction have been documented among ISS crewmembers. These changes appear to be due to naturally occurring, accommodative changes that may be exacerbated by the small volume of spacecraft cabins. Vascular engorgement of retinal support layers also appears to play a role.

The ISS will serve as the platform used to identify risk factors affecting crewmembers' vision, underlying pathophysiology, and mitigation strategies for maintaining crew vision during long-duration missions. If necessary, the ISS will then be used to validate the countermeasures defined for mitigating impaired vision.

***Risk of impaired ability to maintain control of vehicles and other complex systems:*** It has been shown that long-duration spaceflight alters sensorimotor function, which manifests as changes in locomotion, gaze control, dynamic visual acuity, and perception. These changes have not been specifically correlated with real-time performance decrements. This risk must be better documented, and changes must be better correlated with performance issues.

The ISS will be used to gather the data required to define the research that might be needed to enable future exploration operations. This data includes the Space Station Remote Manipulator System, docking, and glove box operations; Soyuz landings; and performance related to neurosensory dysfunction. If countermeasures for long-duration lunar or Mars missions are warranted, the ISS will be required for countermeasure validation.

### **3.1.3 Exploration Medical Capability**

***Risk of inability to adequately treat an ill or injured crewmember:*** To provide the broadest possible medical treatment capability, NASA will use the ISS to develop and test crew health maintenance technologies, making the best possible use of limited mass, volume, power, and crew training. For example, this includes analyzing urine, blood, and saliva in real-time; using smaller, lighter, and more reliable and user-friendly technologies for advanced medical life support; and validating technology to generate water for injection.

A current ISS study for this risk is a test of use of ultrasound to monitor fluid shifts that occur early in flight for both medical operations and future research.

### **3.1.4 Behavioral Health and Performance**

***Risk of performance errors due to sleep loss, circadian desynchronization, fatigue, and work overload:*** Operational requirements of spaceflight exposes astronauts to change in circadian rhythm and new, inferior crew accommodations for sleep resulting in fatigue during spaceflight which may jeopardize health and performance. NASA will use the ISS to assess artificial and transmitted light exposure on performance to quantify individual vulnerability to sleep loss, circadian dynamics, work/sleep schedules, 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. Current ISS experiments - “Sleep-Wake Actigraphy” and “Light Exposure during Spaceflight (Sleep)” will examine the effects of spaceflight on the sleep-wake cycles of the astronauts during Space Shuttle and long-duration ISS missions.

**Risk of behavioral and psychiatric conditions:** The Astronaut cadre and its flight crew are some of the most capable, highest-performing sets of individuals in the world. However, behavioral issues are inevitable among groups of people, no matter how well-selected and trained. Spaceflight demands can heighten these issues.

The ISS can be used to simulate the transit environment to Mars, in order to characterize the risk of behavioral and psychiatric conditions that might 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. A current ISS experiment, “Behavioral Issues Associated with Isolation and Confinement: Review and Analysis of Astronaut Journals”, is quantifying the effect of isolation to help NASA design equipment and procedures to allow astronauts to best cope with isolation and long-duration spaceflight.

**Risk of performance errors due to poor team cohesion, performance, and psychosocial adaptation; inadequate selection/team composition and training:** Risk of performance errors due to poor team cohesion and performance, inadequate selection/team composition, inadequate training, and poor psychosocial adaptation have not been determined. Fortunately, crews aboard the ISS and their mission-control counterparts on the ground performed superbly under difficult conditions.

The ISS will be used to validate methods and technologies that monitor the crew for performance errors due to poor team cohesion and performance, inadequate selection/team composition, inadequate training, and poor psychosocial adaptation. Current studies 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, and the most effective methods for mitigating stress and deteriorated morale to optimize performance (exercise, food, privacy, and entertainment).

### **3.1.5 Space Human Factors and Habitability**

**Risk of inadequate food system:** Nutrition, and to a great extent food, is an important part of the overall capability to keep crews healthy and productive during spaceflight. 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. An example of such an issue would be excessive weight loss during long-duration spaceflight, which could affect individual performance in a number of areas during spaceflight.

The ISS will be used to validate a food system that provides safety, nutrition, and acceptability. ISS research will test the stability of nutrients in food when exposed to the spaceflight environment. In addition, research will test to determine the effects of isolation and length of mission on food acceptability; changes in the sense of taste and palatability of



food in microgravity; and the affect of food technology on mission resources such as mass, volume, power, and crew time.

A study on the ISS addressing this risk, “Assessment of Nutrient Stability in Space Using Flight and Ground-based Simulation of Spacecraft Environmental Factors”, studies the effect of the spaceflight environment (radiation, vibration, etc) on complex organic molecules, such as vitamins and other compounds in food, so that more stable and reliable nutritional food systems suitable for future long-duration missions to the moon and Mars can be developed.

### **3.2 Physical Sciences Exploration Research**

The goal of physical sciences exploration research is to investigate the underlying, gravity-dependent phenomena useful and often essential for advanced spaceflight technologies. Results from these experiments may provide the key to increasing Technology Readiness Level (TRL) of these technologies. The two important physical sciences areas that act as systems-level drivers for exploration systems are fluid management and combustion.

Our inability to accurately predict the intricacies of two-phase flow phenomena, particularly in microgravity, has compelled us to use technologies based on single-phase systems that often result in a significant mass penalty. Fire detection and protection, while important for crew safety, will also drive the life support systems. The following section describes the rationale for the selection of relevant experiments, in addition to providing a brief overview of the experiments and subsequent impacts.

#### **3.2.1 Fluids**

Fluid experiments will investigate multiphase flow, phase change, and heat transfer phenomena that provide the underpinning for propellant storage, energy transport, thermal management, power generation, and life support systems. Areas of investigation include fluid mixing, phase separation, and capillary driven shapes and flows. The low gravity data will be used as a benchmark for validating numerical and analytical models.

The “Capillary Flow Experiment”, which investigates equilibrium liquid-vapor interface configurations and capillary driven flow in vane gaps for propellant tanks, and is currently being tested on the ISS, will provide the basics of fluid management in propellant tanks.

The “Zero Boil off Tank Experiment (ZBOT)” will investigate effective methods to minimize self-pressurization of cryogenic fluid, and subsequent loss of fluid through venting. ZBOT 2 will implement active cooling as a technique to provide long-duration, ventless storage of cryogenes.

The “Capillary Channel Flow” experiment will investigate the limit of capillary-driven flow to provide gas-free propellant to thrusters. Liquid-gas phase separation experiments will investigate both active and passive techniques for phase separation in microgravity. The “Capillary Flow Experiment-2” will demonstrate how gas bubbles can be successfully separated passively from liquid using capillary forces and container geometry.

The “Two Phase Flow Separator for Thermal Management” experiment will demonstrate techniques to successfully separate the gas phase from the liquid phase in microgravity, using active flow separation. Phase separation is required in two- phase thermal management and power systems, and to obtain the highest reliability and performance of these systems. Two pool boiling experiments will also provide significant information on nucleate pool boiling

characteristics, including the heat transfer coefficient and limiting cases of flow boiling critical for safe operation of devices, such as in the event of a pump failure and subsequent loss of flow.

The “Constrained Vapor Bubble” experiment will study flow induced by capillary forces, and establish conditions for optimum performance of a heat pipe. By using an innovative design, this experiment will enhance the performance of future heat pipe systems by eliminating the need for wicks, and allowing volume to mass efficient packing geometry (from cylindrical to honeycomb design).

### **3.2.2 Combustion**

Combustion experiments on the ISS will investigate smoke detection, fire suppressants, and the flammability of materials in spacecraft conditions. The “Smoke and Aerosol Measurement” experiment and its possible successor experiment will lead to the development of spacecraft fire detectors to provide accurate, early fire warning, while decreasing the frequency of false alarms.

The “Flame Extinguishment” experiment will assess the effectiveness of fire suppressants in microgravity in various cabin atmospheres, enabling development of design criteria for spacecraft, fire suppression systems. The flammability of materials used in spacecraft is currently assessed based upon normal gravity flammability properties.

The “Flammability Assessment of Materials for Exploration” experiment will study the flammability of materials in practical geometries and atmospheres in microgravity. Three geometries will be considered (flat plate, stagnation, and wake flows), using a sample placed in an unconfined jet flow. These tests will improve our understanding of low-gravity flammability, enabling more accurate prediction of low-gravity flammability of materials from normal gravity test results.

### **3.3 Physical Sciences Non-Exploration Research**

Physical science research on the International Space Station (ISS) will include investigations ranging from basic fluid physics to combustion and materials science, such as the study of phase separation in colloidal fluids, soot emission from flames, and crystal growth in semiconductors. ISS research will initially focus on completing a core group of small and diverse microgravity experiments that are near completion, or ready to be manifested for flight to ISS.

The next series of experiments that are under development involve generally larger payloads with international collaboration, and will use the numerous ISS facilities. This collaboration maximizes return from ISS research through sharing facilities in the U.S. Destiny laboratory, and also sharing ISS facilities in the ESA Columbus Laboratory facilities, the Japanese Experimental Module (JEM) facilities, and the JEM Exposed Facility. Existing NASA and international partner facilities on the ISS that support exploration-related research will also be leveraged to support non-exploration research. These facilities include the Fluids and Combustion Facility and the Microgravity Science Glovebox.

### **3.3.1 Fluids**

Fluid experiments will focus on colloidal and liquid crystal systems, using the existing Light Microscopy Module (LMM) hardware in the Fluids Integrated Rack (FIR) aboard the ISS. The “Colloids” experiment will study small colloidal particles used to model atomic systems, and to engineer new systems without the gravitational effects of sedimentation and particle jamming that make these experiments impossible to perform on Earth. For example, billions of nano-pumps can be created from a single initial pump, using self-replication techniques.

The “Observation and Analysis of Smectic Islands in Space” experiment will exploit the unique characteristics of freely-suspended liquid crystals in a microgravity environment. These systematic studies will provide us with clues to improve the contrast, resolution, and faster response of the liquid crystal based on very high-definition display devices that are currently used on the helmet-mounted and heads-up display systems.

### **3.3.2 Combustion**

The following combustion experiments are primarily aimed at improving the efficiency and pollution control of practical combustors here on earth. The “Smoke Point in Co-Flow” experiment will improve the understanding of soot emission from jet flames by measuring smoke-point properties of jet diffusion flames in a co-flow environment, and improve the understanding of and ability to predict heat release, soot production, and emission in microgravity fires.

The “Flame Extinguishment” experiment will study droplet combustion to address soot formation, bi-component fuels combustion, flow field effects, and practical fuel combustion. All of these topics will further our understanding of droplet combustion, enabling improved efficiency of practical combustors.

The “Advanced Combustion via Microgravity” experiments are gaseous combustion experiments that will provide data to better control soot production and flame stability in practical combustors. These investigations support improved fuel efficiency and pollutant reduction in practical combustion systems by pursuing enhanced combustion through targeted flame design.

### **3.3.3 Materials**

These material experiments will aim to improve the understanding of impurity incorporation and microstructure formation in semiconductor and metallic materials. The “Crystal Growth of Ternary Compound Semiconductors” experiment will investigate the processes in the fluid phases, liquid, and vapor, such as buoyancy driven convection, which can result in inhomogeneities, impurities, and defects in the resulting crystal. Such semiconductors are of vital national interest as sensors in x-ray telescopes and for homeland security, and as substrate materials for infrared sensors.

The “Quasi-Crystalline Undercooled Alloys for Space Investigation” examines the fundamental mechanisms and intermediate structures formed as a liquid transforms to a solid, while probing novel intermediate quasicrystal structures, which have considerable industrial potential for hydrogen storage.

The “Dynamic Selection of Three-Dimensional Interface Patterns in Directional Solidification” experiment will improve the understanding of the dynamics that lead to

uniform and reproducible three-dimensional structures, such as are required in today's high-strength and increasingly complex alloys.

### **3.4 Non-Exploration Life Sciences Research**

Since the NASA Authorization Act of 2005 was passed, a number of flight experiments that had been prioritized lower during reviews, and were planned to be eliminated as a result of the Exploration Systems Architecture Study and subsequent budget reductions, were reprioritized and reinstated using both the Space Shuttle and ISS capabilities for conducting non-exploration research. These experiments include investigations ranging from microorganism and cellular research to plant and animal (non-rodent) research. Specifically, these investigations were conducted on spaceflight effects on microbial molecular, morphological and virulence changes, fly immune system changes, immune cell culture studies on cell activation, and an investigation on plant responses to light and microgravity. The Agency has also planned plant investigation into the fundamental mechanisms of wood cell formation in space, and an immune cell culture study. In many cases, these investigations involve collaborations with our international partners.

NASA intends to augment opportunities for flying non-exploration biological research payloads by using domestic and Russian free flyers, and by leveraging resources with Department of Defense, industry, academic, and international partners.

### **3.5 Development and Testing of Systems for Long-Duration Space Missions**

#### **3.5.1 Materials Survivability, Inspection, and Repair in the Space Environment (MSIR)**

The MSIR program will test and evaluate new materials, components, and processes that need an in-space external environment evaluation. The space environment poses many hazards to the exposed surfaces of spacecraft, including intense ultraviolet radiation, corrosive attacks from atomic oxygen, radical temperature swings, and damage from micrometeoroids and orbital debris.

NASA studies of the exposure of materials to the space environment for long periods of time have taken advantage of the Russian Space Station Mir and the ISS as a location to place, mount, and retrieve sets of test materials. The Materials International Space Station Experiment (MISSE) has two Passive Experiment Carriers (PECs), with approximately 900 specimens that were mounted outside the ISS airlock in August 2001 and returned in August 2005. A new PEC was mounted on ISS in August 2005. Two more PECs were brought up by Space Shuttle flight STS-121/ULF1.1, and two additional PECs are planned to be brought to ISS on a subsequent Space Shuttle flight. Items to be tested include proposed hatch seal materials for the Orion Crew Exploration Vehicle. Analyses of exposed sample survivability will be conducted upon return of samples.

#### **3.5.2 Environmental Monitoring and Control (EMC)**

Currently, there are limited capabilities on the ISS to perform real-time monitoring of air and water quality. Lack of timely chemical and microbial detection in the crew atmosphere, or elsewhere in the air processing system, can lead to delayed response by the crew or flight controllers, or by automated response equipment, leading to increased hazards. The EMC Program will provide more reliable and capable, compact, real-time monitoring technology for microbial, air and water contaminants.

The program will develop a suite of miniaturized sensors for environmental monitoring of crewed vehicles and habitats. These sensors will operate autonomously, and with minimal or no crew intervention. The ISS will be utilized to demonstrate and validate that the developed technologies will operate in a “Relevant Environment” autonomously and maintenance free for a period of greater than three months. The focus is on EMC technologies that have been matured to a Technology Readiness Level appropriate for “Technology Demonstration” on the ISS.

Specific sensors, if successful, will be carried forward beyond a technology demonstration to operational status. Sensors being developed include the following: Vehicle Cabin Air Monitor (VCAM); Electronic Nose, which is an event detector for ISS air quality; Colorimetric Solid Phase Extraction Water Monitor, which will measure silver and iodide in ISS water; and Lab-On-a-Chip (LOCAD), which is a portable test system that will monitor surfaces on the ISS for bacterial contamination.

#### 4.0 Scientific Coordination

All of the scientific activities that are currently planned as a part of both the exploration and non-exploration portfolio have been based on the recommendations of external committees (National Academies and NASA Chartered Panels). They take into account the available experimental facilities, upmass and downmass capabilities, intrinsic scientific and technical merit, the retirement of critical risks, and the contribution to the advancement of key scientific questions. In cases where NASA deems it fit to undertake directed research to answer a critical question, the scientific goals and the associated experimental protocols are vetted and peer-reviewed by external non-advocate review panels.

#### 5.0 Scientific Procurement

In order to address research and technology development questions, the Agency issues NASA Research Announcements (NRAs) that are open to the intra-mural and extra-mural scientific community. The content of these research announcements is derived from the critical questions and gaps that need to be answered using the research platforms available. All of the proposals submitted in response to these announcements are peer-reviewed and evaluated by external, independent review panels for intrinsic scientific merit. NASA reviews these proposals in the context of research priorities and programmatic relevance, and awards are made based on research priorities and available funding.

It is expected that NASA will release NRAs periodically. These announcements will solicit for research opportunities in a number of areas including research on the ISS. The National Space Biomedical Research Institute (NSBRI) will also solicit for research in areas that address the risks/gaps for human spaceflight. The NSBRI research announcements will complement those of the HRP. In the realm of physical and fundamental life sciences, research announcements will be considered when a need exists for new science to be deployed and if fiscal conditions permit. Currently NASA has a fairly long queue of peer-reviewed investigators that are scheduled to conduct research on the ISS in the future.

## 6.0 Research Plans

One of the major responsibilities of science management within the Advanced Capabilities Division (ACD) is to participate in the development of research plans by its constituent programs.

The science management team within the HRP participates in element and project plan development by designing and maintaining the research plans, and ensuring that the research content in these plans meets HRP requirements, as documented in the Human Research Program Requirements Document (PRD) (HRP-47052). This PRD is used to guide research planning, and serves as a key document used to develop the aforementioned research plans.

The Human Research Program Utilization Plan for International Space Station describes the experiments to be conducted by the HRP on the ISS. This plan elucidates the approach used by the HRP, and the assumptions made in deciphering the ISS utilization strategy to retire the 25 risks baselined by the program as best resolved on the ISS. This plan also takes into account factors such as available crew time, number of available subjects, upmass and downmass capabilities, and potential follow-on research that would be required to retire a risk and validate appropriate countermeasures.

In the Exploration Technology Development Program (ETDP), the ISS Exploration and Non-Exploration Research Project plan combines several sub plans into one comprehensive document. The sub plans include the ISS Physical Science Exploration Research Plan, the ISS Physical Science non-Exploration Research Plan, and the Non-Exploration Life Science Research Plan.

The Physical Science Exploration Plan includes experiments necessary to provide knowledge to enable informed decision making by Constellation program and project managers for the systems and subsystems of their vehicles. An example of such an experiment is the “Smoke and Aerosol Measurement” experiment, which sought to examine the morphology of smoke particles in the microgravity environment, and test how the smoke particles affected different smoke detectors. The data from this experiment will be useful for the preliminary design review of the Orion crew exploration vehicle.

The Physical Science Non-Exploration Research Plan includes physical science conducted for its intrinsic value. Such experiments have been selected to use existing research capabilities on ISS.

## 7.0 Reviews

The *ISS Exploration and Non-Exploration Research Project Plan* and the *Human Research Program Utilization Plan for the International Space Station* are elements of the Exploration Technology Development Program and the Human Research Program of the Exploration Systems Mission Directorate (ESMD). Both programs are subject to internal and external reviews for research and technology development proposals prior to implementation and for implemented proposals, annual reviews are held until completion. The external component of these reviews may involve external advisory groups such as the National Research Council (NRC). Additional annual reviews are completed as part of NASA’s budget formulation and review cycle and technical reviews are held in accordance

with NPR 7120.8. Currently, ESMD's ETDP and its ISS Exploration and Non-Exploration Research project are being reviewed by an NRC panel, per Congressional directive and Agency policy.

Starting in February 2008, the Institute of Medicine will review all HRP exploration risks and assess whether the risks are accurate and the supporting evidence base is complete. Also, in June of 2008, the HRP intends to hold a Program Implementation Review (PIR). This bi-yearly review will cover the HRP management processes, and alignment of the HRP technical content, schedule and budget.

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## Appendix B: Acronyms and Terms List

ACME	Advanced Combustion via Microgravity Experiments
APEX/Cambium	Advanced Plant Experiments on Orbit
BCAT-4	Poly Binary Colloidal Alloy Test - 4: Polydispersion
Bisphosphonates	Bisphosphonates as a Countermeasure to Spaceflight Induced Bone Loss)
Braslet	Validation of On-Orbit Methodology for the Assessment of Cardiac Function and Changes in the Circulating Volume Using Ultrasound and Braslet-M Occlusion Cuffs
BXF	Boiling Experiment Facility
CCF	Capillary Channel Flow
CFE	Capillary Flow Experiment
CSLM-2	Coarsening in Solid Liquid Mixtures-2
CPSE	Colorimetrics Solid Phase Extraction
DAFT	(Dust and Aerosol Measurement Feasibility Test
DSIP	Dynamical Selection of Three-Dimensional Interface Patterns in Directional Solidification
EMCS	European Modular Cultivation System
E Nose	Electronic Nose
Epstein-Barr	Spaceflight Induced Reactivation of Latent Epstein-Barr Virus
FIT	Fungal Pathogenesis, Tumorigenesis, and Effects of Host Immunity in Space
FLAME	Flammability Assessment of Materials for Exploration
FLEX-2	Flame Extinguishment Experiment
Foot	Foot Reaction Forces During Spaceflight
Foton M#	Russian Foton Rocket used for Free Flyer Experiments
Genesat	GeneSat-1 Free Flyer Technology Demonstration Experiment
GRAD FLEX	Gradient Driven Fluctuations Experiment

GTS	Crystal Growth of Ternary Compound Semiconductors
InSPACE-2	Investigating the Structure of Paramagnetic Aggregates from Colloidal Emulsions - 2
Journals	Behavioral Issues Associated with Isolation and Confinement: Review and Analysis of ISS Crew Journals
Leukin	Role of Interleukin-2 Receptor in Signal Transduction and Gravisensing Threshold of T-Lymphocytes
LMM/CVB	Light Microscopy Module/Constrained Vapor Bubble
LOCAD PTS	Lab-on-a-Chip Application Development Portable Test System
MDCA/FLEX	Multi-User Droplet Combustion Apparatus/Flame Extinguishment Experiment
MED Water	Medical Grade Water
Microbe	Effect of Spaceflight on Microbial Gene Expression and Virulence
Midodrine-Long	Test of Midodrine as a Countermeasure Against Post-flight Orthostatic Hypotension - Long
Mobility	Promoting Sensorimotor Response Generalizability: A Countermeasure to Mitigate Locomotor Dysfunction After Long-Duration Spaceflight
Nutrition	Nutritional Status Assessment
OASIS	Observation and Analysis of Smectic Islands in Space Colloids Experiment
PADIAC	PATHway Different ACTivators
PFE-OUM	Periodic Fitness Evaluation with Oxygen Uptake Measurement
PKINASE	Mechanisms and functional consequences of protein kinase C isoform translocation inhibition in monocytes exposed to microgravity
PMZ	Bioavailability and Performance Effects of Promethazine During Spaceflight
POEMS	Passive Observatories for Experimental Microbial Systems
QUASI	Quasi-Crystalline Undercooled Alloys for Space Investigations

Renal Stone	Renal Stone Risk During Spaceflight: Assessment and Countermeasure Validation
SAME	Smoke Aerosol Measurement Experiment
SEP	Two Phase Flow Experiment
SHERE	Shear History Extensional Rheology Experiment
SPEGIS	Streptococcus pneumoniae Expression of Genes in Space
SPICE	Smoke Point in Co-Flow Experiment
Stability	Stability of Pharmacotherapeutic and Nutritional Compounds
SWAB	Surface, Water and Air Biocharacterization - A Comprehensive Characterization of Microorganisms and Allergens in Spacecraft Environment
VCAM	Vehicle Cabin Atmospheric Monitor
VIBE	Vibrational Inhibition of Bone Erosion - A Low-Intensity Mechanical Countermeasure to Prohibit Osteoporosis in Astronauts During Long-Term Spaceflight
ZBOT	Zero Boil-off Tank Experiment
ZBOT-2	Zero Boil-off Tank Experiment-2
ZBOT-3	Zero Boil-off Tank Experiment-3