NASA/SP–2004–6113

Bioastronautics Roadmap

A Risk Reduction Strategy for Human Space Exploration

February 2005

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Executive Summary

Bioastronautics as a discipline is the study of biological and medical effects of space flight on humans. It is represented by an ongoing set of collaborative relations, spanning research and technology development, operational, and policy issues related to the health and performance of the human during space flight missions, and afterwards. Bioastronautics activities are carried out across several Mission Directorates and a Staff Office, (i.e., the Exploration Systems Mission Directorate, the Space Operations Mission Directorate, and the Office of the Chief Health and Medical Officer). The Bioastronautics Exploration Research and Technology Office at Johnson Space Center, has responsibility for the Roadmap as a product.

In Bioastronautics the human is considered to be a critical system of space flight in the same way that propulsion, thermal, and power are critical systems of space flight. Like those systems, the operating bands[1] and requirements for the performance and health of the human system must be understood, controlled, and specified, as well as optimally integrated with other systems. The human system includes all of the crewmembers, both individually and collectively, and their requirements for physical and behavioral health in the context of the defined missions. The requirements for the missions are the result of an iterative developmental process based on the increased knowledge and technology maturation that results from addressing the risks associated with the human system.

The Bioastronautics Roadmap guides the prioritized research and technology development that, coupled with operational space medicine, will inform: (1) the development of medical standards and policies; (2) the specification of requirements for the human system; and (3) the implementation of medical operations. The Roadmap provides information that helps (1) establish tolerances (i.e. operating bands or exposure limits)[2] for humans exposed to the effects of space travel and develop countermeasures to maintain crew health and function within those limits; and (2) develop technologies that make human space flight safe and productive.

The Roadmap is the framework used to identify and assess the risks of crew exposure to the hazardous environments of space. It guides the implementation of research and technology strategies to prevent or reduce those risks and defines processes for accommodating new information and technology development. As a research management tool for risk identification, assessment, and reduction, the Roadmap provides information for making informed decisions about determining research priorities, setting exposure standards, and allocating resources. The outcome-driven nature of the Roadmap makes it amenable for

1 Operating bands represent an acceptable range of performance or functioning that is bounded at both the upper and lower limits and anything outside those limits is unacceptable. Operating bands are used in the Roadmap for the system performance and efficiency risks associated with life support and habitation systems. Exposure limits are used for the human health risks and refer to setting an acceptable maximum decrement or change in a physiological or behavioral parameter, as the result of exposure to a space flight factor over a given length of time (e.g. life time radiation exposure). Exposure limits are based on the impact the decrement or exposure has on the capability to perform assigned tasks, and its implication for lifetime medical status.

2 As defined in the Bioastronautics Strategy (NASA Headquarters, January 2003), "Acceptable levels of risk define the tolerances, i.e., exposure limits or desirable operating bands, for the human -system."

assessing the focus, progress and success of the research and technology program with regard to ensuring the vitality, health and productivity of the human system. The Roadmap is also a tool for communicating the inherent risks and complexities, priorities, and progress associated with human aspects of exploration missions. As pointed out by the National Research Council however, no set of guidelines or procedures can substitute for scientific fairness, rigor, and flexibility in coping with dynamic risk situations (Fineberg, Committee on Risk Characterization, National Academy Press, 1996).

Bioastronautics Roadmap Objectives

The goal of the Roadmap is to reduce risk through effective and efficient mitigation solutions developed from a focused research and technology development strategy. The Roadmap objectives are to:

- Identify and assess risks for human space exploration missions
- Prioritize research and technology, and communicate those priorities
- Guide solicitation, selection and development of NASA research and technology (ground and flight) and allocation of resources for development of exploration mission deliverables
- Assess progress towards reduction and management of risks through appropriate development of deliverables and products
- Deliver the appropriate products and knowledge for developing:
    - Standards
    - Requirements
    - Clinical tools and capabilities for diagnosis and treatment of illness and injury
    - Inputs to mission, task, and vehicle design
    - Countermeasures
    - Training and in-flight medical protocols
    - Specific technologies
    - Components and systems with increased efficiencies

Bioastronautics Roadmap Contents

The key elements of the Roadmap represent both content and process. The basic contents are the risks, their associated research and technology questions, and the deliverables. Its major processes include risk identification and assessment.

Mission requirements provide the context for identification and assessment of risks. The development of mission requirements for the human system will follow an iterative path among the collaborating Mission Directorates and Staff Offices as research, policies, and capabilities converge. The Roadmap defined three Reference Missions to provide the context to identify and assess the risks in the interim:

1. A one-year International Space Station (ISS) mission
2. A month-long stay on the lunar surface

3. A 30-month journey to Mars

For purposes of the Roadmap, a *risk* is defined as the conditional probability of an adverse event from exposure to the space flight environment; a *risk factor* is defined as a predisposing condition that contributes to an adverse outcome. The Roadmap focuses on two types of risks: health and medical risks, and engineering technology and system performance risks.

The research and technology questions (R&TQ) in the Roadmap represent issues that must be sufficiently addressed either to resolve questions or retire a risk, or to inform an accepted risk decision. Deliverables are the specific products that have been identified as desirable outcomes or solutions to the R&TQ, and have date-specific expectations and mission milestones associated with their development. For planning purposes, two of the key dates driving Bioastronautics research and technology deliverable development are: (1) the retirement of the Space Shuttle in 2010; and (2) the end of NASA's commitments to the ISS in 2016. The Roadmap is the integrated product of all of these elements and illustrates the strategy for optimizing human health and performance to enable exploration missions.

Five crosscutting areas integrate the 15 individual disciplines comprising the Roadmap. The crosscutting areas are: Human Health and Countermeasures (HHC), Behavioral Health and Performance (BHP), Radiation Health (RH), Autonomous Medical Care (AMC), and Advanced Human Support Technologies (AHST). HHC mainly addresses development of countermeasures for the deleterious physiological effects of space flight as well as establishment of medical standards and requirements. The focus of BHP is to optimize psychosocial and behavioral functioning of the crew and ensure their overall readiness to perform. RH focuses on setting the requirements for radiation shielding and monitoring, and reducing the uncertainties for predicting cancer and other radiation health risks with the aim of increasing allowable crew time in space. AMC addresses the capability to monitor, diagnose and treat injury or illness during missions, with an emphasis on increasing the use of autonomous operations. AHST focuses on engineering requirements and solutions for human habitats.

Bioastronautics Roadmap Processes

All of the Roadmap risks were identified initially through deliberations by discipline teams which included review of recent research results as well as previous advisory committee reports. The Risk Data Sheets (RDS) were developed to serve as the database for the Roadmap.

Risk assessment was derived through an iterative process of analysis and deliberations among key stakeholders including: the discipline teams, the Bioastronautics Science Management Team (BSMT), the Chief Health and Medical Officer (CHMO), the Astronaut Office, flight surgeons, and research management. The last set of deliberations included a review of comments provided by the research community in response to a Web based query.

The BSMT adopted a numerical categorization to communicate the relative priorities across the 45 risks. Each risk was assessed for each of the three Reference Missions for nominal conditions and operations only – similar assessment of additive or cascading risks is left as future work. In addition, five overarching issues were identified:

- The need for ground-based integrated testing involving humans and spacecraft systems (Environmental Life-Support testing, countermeasure evaluation and validation, and end-to-end testing)
- Actual risks must be operationally based, not research-based
- Key human system requirements (e.g., radiation shielding, habitability standards, etc.) should be incorporated into spacecraft and mission designs early in the process
    - Designers and bioastronautics experts should work together to optimize accommodation of the human element
- All Human Health and Performance support hardware (Exercise equipment, environmental monitoring hardware, medical diagnostic and therapeutic equipment) must be designed to assure reliability
- An integrated approach is required to develop efficient engineering solutions for the human support systems that avoid excessive resource costs (i.e. efficient in the sense of low mass, low power consumption, low consumables requirements, high reliability, and low maintenance)

Risk Assessment and Management

Assessment and management of the Roadmap research and risks depends on development, selection and implementation of the right mitigation strategies and other identified Roadmap deliverables. The Roadmap uses a project management approach to achieve its objectives.

The Bioastronautics Roadmap Control Panel (BRCP) is responsible for maintaining the content of the Roadmap (and its companion Web site – http://bioastroroadmap.nasa.gov). The Human System Working Group (HSWG) has responsibility for the risk mitigation approval process and approves the baseline document. In addition, the HSWG assesses and baselines exposure limits for human health and performance, and operating bands for life support and habitation systems, and then recommends adoption of those limits and bands to the CHMO. The CHMO is responsible for developing the standards and requirements for the human system. The Exploration Systems Mission Directorate (ESMD) and Space Operations Mission Directorate (SOMD) solicit and fund the research and technology development activities.

Forward work for the Roadmap includes: identification of the deliverables for each of the exploration missions; revision of the Roadmap as mission requirements are better defined; assessment of the consequences of second-order, additive, or cascading risk manifestations; development of program evaluation tools and metrics; re-establishment of the BRCP; continued development of risk assessment and quantification tools; and, better definition of an implementation plan.

Conclusions

The following conclusions were derived from recent Roadmap refinement activities:

1. Given the time constraints, the Roadmap activities must focus on operational issues, and solutions to operational problems, to support an outcome-oriented approach.

2. High priority health and medical issues for a mission to Mars include: (a) maintaining behavioral health and psychosocial functioning; (b) providing radiation protection; (c) addressing the requirements for AMC capabilities; (d) minimizing bone loss; (e) maintaining sensory motor capability to perform tasks after landing; (f) ensuring adequate nutrition; (g) monitoring and controlling environmental contaminants; and, (h) providing efficient and reliable health and medical support hardware. For a lunar mission the health and medical issues are: (a) development of environmental life support and habitation technologies; (b) providing capabilities for remote medical care; and (c) providing adequate radiation protection.

3. The identified set of risks includes some that have been well documented and proven and others that have not been documented. Further quantification of risks, where appropriate, is an important priority. For example, in the near term it is important to determine whether or not serious cardiac dysrhythmia is a risk associated with prolonged space flight.

4. While a one-year stay on the ISS presents a generally lower risk than the other two missions, the ISS is an important research platform for reducing the risks for Moon and Mars missions.

5. It is imperative that a new paradigm be adopted to accomplish the objectives of the Roadmap that further integrates flight and ground activities and optimizes flight resources as it emphasizes the human system. The Roadmap will use a project management approach to meet its goals and objectives and effectively manage its risks.

6. Effective measures of success in identifying and assessing risk must be defined with a clear goal, and project teams along with management must use these defined measures to assess and communicate progress.

7. Participation of the key stakeholders in the deliberation process is integral for risk identification and assessment. It is essential that astronauts and flight surgeons participate in the continued evolution of the Roadmap.

8. Communication, integration, and coordination among intramural and extramural biomedical researchers, technology developers, flight surgeons, astronauts and NASA management and the field centers are essential for the success of the Roadmap.

9. It is a recommendation of the BMST that a strategy be developed to address the five overarching issues for the human system.

1.0 INTRODUCTION

Bioastronautics as a discipline is the study of biological and medical effects of space flight on humans. It encompasses research, operations, and policies related to the risks associated with human space flight. The human is as much an integral system of space flight as are propulsion, thermal, or power; and operating bands and exposure limits for the human system must be defined and controlled (through countermeasures and other means) to ensure its overall performance and functioning within the larger spacecraft system. "Operating bands" define an acceptable level of performance and functioning for the life support and habitation risks in the Roadmap that is bounded at the upper and lower levels; anything outside those limits is unacceptable. "Exposure limits" are used for the human health risks and specify an acceptable maximum change (whether increment or decrement) in a physiological or behavioral parameter, as the result of exposure to a space flight factor over a given length of time (e.g. life time radiation exposure). Exposure limits are based on the impact the exposure has on the capability to perform assigned tasks, and its implication for lifetime medical status.

The Roadmap was established to be the framework for identifying and assessing the risks of crew exposure to the hazardous environments of space. As a research management tool for risk identification, assessment, and reduction, the Roadmap provides information for making informed decisions about determining research priorities, setting exposure limits, and allocating resources. The Roadmap is an outcome-driven strategy for delivering products to understand, prevent, and reduce the risks that potentially limit human space flight today, and enable exploration. The Bioastronautics operational and research communities will work together to establish standards, define safe operating bands or duration-based exposure limits to the space environment for the human system, develop technologies that make human space flight safe and productive, and develop countermeasures that maintain crew capability and function during and after space flight. It is important to provide this information to mission planners who establish requirements for space vehicles and habitats. Ensuring the health, safety and performance of those exposed to the space environment requires a research and technology portfolio that spans clinical, basic and applied research and technology development activities, as well as the operational and policy issues related to human space flight.

The Roadmap will evolve to accommodate new information and technology development, and will enable formal critical path analyses in the future taking into account benefits and costs associated with alternative critical paths and risk reduction options.

2.0 ROADMAP HISTORY

The Johnson Space Center (JSC) Space and Life Sciences Directorate (SLSD) first initiated the Bioastronautics Roadmap in 1997, as the "Critical Path Roadmap." In 1998, participation was expanded to include the National Space Biomedical Research Institute (NSBRI) and other members of the external community. The Roadmap began as an iterative approach by discipline experts to identify, analyze, and prioritize the most critical (in the sense of important for the health and performance of the crews during and following space flight) risks confronting human space flight missions. Those risks were based on the most challenging scenario, a human expedition to Mars. The risks and associated research and technology issues were derived using a deliberative process among discipline experts who drew upon recent published research results as well as various advisory committee reports (e.g., NASA Advisory Council, 1992; National Academy of Sciences (NAS) 1987, 1998; National Research Council (NRC) 1993; National Academy of Engineering (NAE) 1997, NASA Countermeasure Task Force, 1997; National Council on Radiation Protection (NCRP) 1989, 1997, 2000).

2.1 Risk Assessment and Management

Risk assessment was based first on the relative ranking by the discipline experts of an identified risk within a discipline. A set of criteria was used to estimate the likelihood of an event and the severity of the consequence(s) of a risk, as well as its mitigation status. As a second step, a separate panel of experts categorized the relative importance of risks across all disciplines, using the discipline experts' assessment and ranking. The basis for identifying and assessing the risks was developed over several years and included:

- Establishing a configuration control process
- Developing and publishing the Bioastronautics Strategy (January 2003)
- Adopting and testing several risk assessment and communication tools
- Developing NASA Research Announcements (NRAs) and task selection procedures based on the Roadmap
- Developing a Web based tool for communicating the risks and research questions - http://bioastroroadmap.nasa.gov

2.2 Bioastronautics Critical Path Roadmap Baseline Document

In 2000, the Bioastronautics Critical Path Roadmap, as it was then called, was baselined and put under configuration control. A total of 55 risks and 250 research questions were documented (BCPR Baseline Document Rev D). The designated discipline team leads submitted specific change requests based on new knowledge of risks and questions, and those were reviewed and dispositioned by the configuration control panel. Corresponding updates to the baseline document and to the companion Web site were implemented. Several subsequent NRA cycles reflected the priorities identified in the document and helped focus on investigator-initiated tasks that were deemed to be relevant and congruent with the risks, research questions, and their priorities. Analyses of program gaps and strengths were undertaken to assist the decision-making process for selection and resource allocation. In 2002, NASA began an effort to prioritize research for the ISS. The Research Maximization and Prioritization Task Force (ReMAP) reviewed the Roadmap approach and products and utilized the Roadmap in their deliberations of the ISS research priorities for the Office of Biological and Physical Research (OBPR).

2.3 Bioastronautics Strategy

The Bioastronautics Strategy was developed and signed in January 2003 by the three collaborating Program Offices: the Office of the Chief Health and Medical Officer (OCHMO), the OBPR, and the Office of Space Flight. The strategy established the goals and objectives for Bioastronautics based on the risk reduction framework of the Roadmap. NASA's Strategic Plan was released in March 2003 and emphasized the role of Bioastronautics in understanding and controlling the human health risks as it set the goal of extending the boundaries and duration of human space flight. In October 2003, the OBPR Enterprise Strategy was published and the Roadmap's outcome-driven risk reduction and management framework served as the basis for several of the organizing questions found in the Enterprise Strategy. In addition, the NASA Space Flight Enterprise, published in November 2003, emphasized the collaborative nature of Crew Health and Safety Program priorities and the OBPR research strategy for effective and efficient risk mitigation solutions.

2.4 Bioastronautics Science Management Team

The Bioastronautics Science Management Team (BSMT), composed of individuals representing Bioastronautics stakeholders, was established in 2003 to provide oversight to the process that would align the Roadmap with exploration mission scenarios. Its members represented the Office of Space Flight, the former OBPR, the Office of the Chief Health and Medical Officer, and at JSC, the Space and Life Sciences Directorate, the Astronaut Office, the Space Medicine & Health Care Systems Office, the Habitability and Environmental Factors Office, the Human Adaptation and Countermeasures Office, and the National Space Biomedical Research Institute (NSBRI). The BSMT was responsible for setting the initial reference mission characteristics that define the context of the risks for the purpose of the Roadmap, reviewing and analyzing the risks and associated questions, developing risk assessment criteria, and participating in the risk rating process. The BSMT utilized discipline teams, or in some cases, multi-disciplinary teams, for the initial identification of the risks, updating those risks and associated questions relative to the three reference missions, assessment of the risk's likelihood and consequences, providing information on the Risk Data Sheets, and participation in workshops and conferences. The role of the BSMT in the Roadmap revision process ended with the baselining of the current document.

3.0 ROADMAP CONTROL AND CONFIGURATION

The Bioastronautics Roadmap is a result of a detailed development and review process. With the establishment of the Vision for Space Exploration, the Roadmap is in use by the Agency elements in support of exploration.

The Human Systems Working Group (HSWG) was established by the ESMD and SOMD, with the concurrence of the CHMO, to support human systems research, technology and operations monitoring the alignment of the human system activities with the Vision for Space

Exploration, promoting cooperation and communication among Mission Directorates and Administration Staff Offices, and coordinating the risk mitigation processes and procedures for the human system. The HSWG has responsibility, as documented in its charter (December 2004), for the risk mitigation approval process, for approval of the baseline Roadmap content, and for establishing the change and configuration control process for this Roadmap.

The Johnson Space Center (JSC) Space Life Sciences Directorate (SLSD) is responsible for supporting and maintaining the content of the Bioastronautics Roadmap and the companion Web site (http://bioastroroadmap.nasa.gov).

4.0 ROADMAP GOALS AND OBJECTIVES

On January 14, 2004, the President announced a new vision for America's civil space program with the following goals: returning the Space Shuttle safely to flight; completing the ISS; phasing out the Space Shuttle when ISS is complete (about 2010); sending a human expedition to the Moon as early as 2015, but no later than 2020; conducting robotic missions to Mars to prepare for future human expeditions; sending a human expedition to Mars on or about the year 2025; and conducting robotic exploration across the solar system. Previously, the Bioastronautics Strategy focused on three reference missions representative of those outlined by the President. The Strategy identified three specific goals for the Bioastronautics Roadmap: reduce and manage risk; increase risk reduction efficiency; and, return benefits to Earth.

The Roadmap is a systematic approach to prevent, control, eliminate or reduce the known risks to crew health, safety and performance during and after long-duration human space flight. As a management tool, the Roadmap is used to inform the decision-making process. Its goal is to reduce risk through effective and efficient mitigation solutions using a focused research and technology development strategy. Its objectives are to:

- Identify and assess risks for human space exploration missions
- Prioritize research and technology, and communicate those priorities
- Guide solicitation, selection and development of NASA research and technology (ground and flight) and allocation of resources for development of exploration mission deliverable
- Assess progress toward reduction and management of risks through appropriate development of deliverables and products
- Deliver the appropriate products and knowledge for developing:
    - Standards
    - Requirements
    - Clinical tools and capabilities for diagnosis and treatment of illness and injury

- Inputs to mission, task, and vehicle design
- Countermeasures
- Training and in-flight medical protocols
- Specific technologies
- Components and systems with increased efficiencies

5.0 KEY ELEMENTS OF THE ROADMAP

The key elements of the Roadmap and their inter-relations are shown in the process flowchart in Figure 5-1, and are described in the following section.

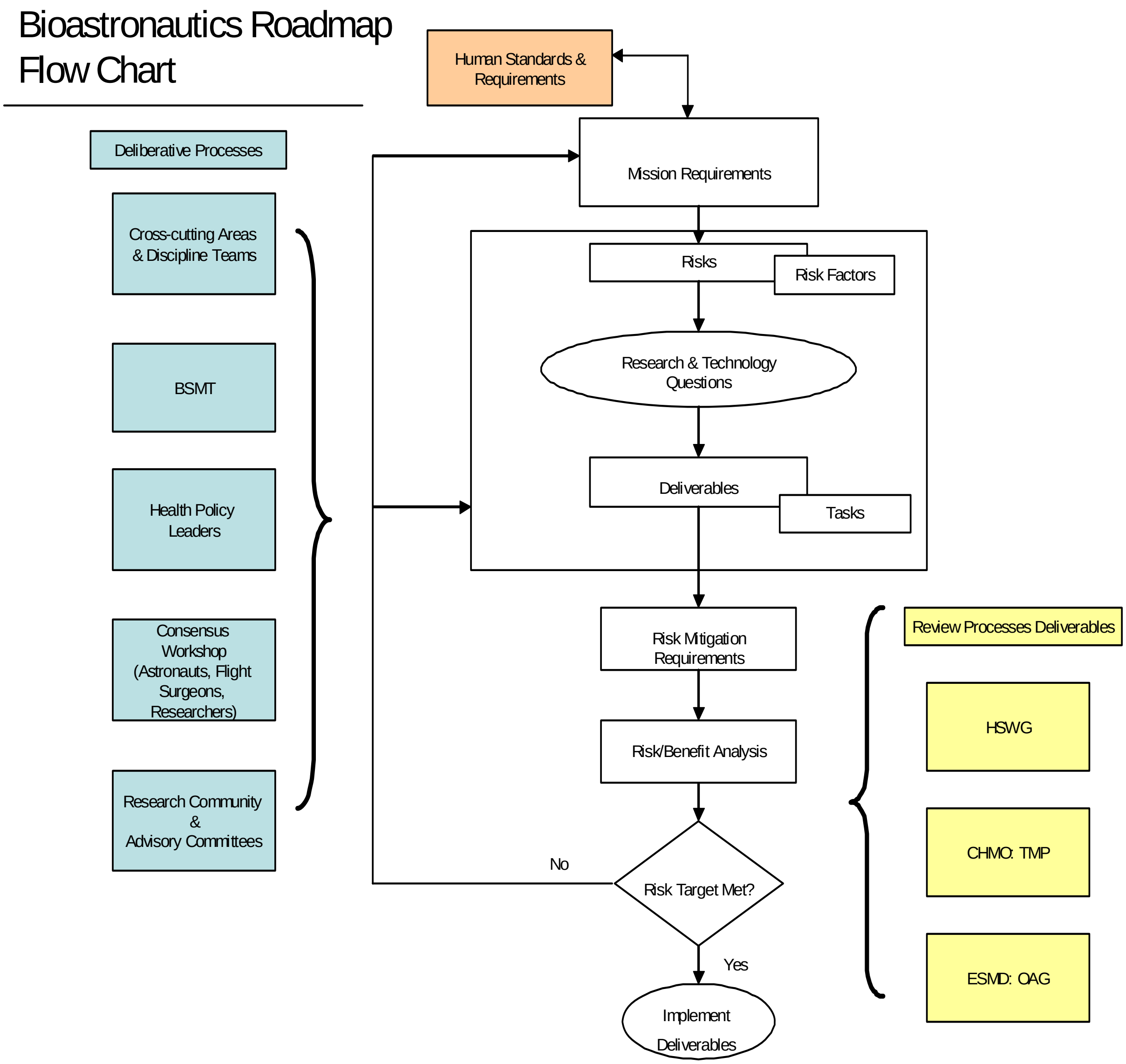

Figure 5-1: The Bioastronautics Roadmap Process Flow Chart

5.1 Setting Reference Mission Requirements

For the purposes of the Roadmap, three Reference Missions were developed to set the context for risk identification and assessment. Mission requirements are the basis for identifying risks and determining their relative priorities, and for establishing medical standards for crew health and performance. The development of mission requirements for the human system follows an iterative path among collaborating NASA Mission Directorates (Exploration Systems and Space Flight Operations) and a Staff Office (Chief Health and Medical Office). The recently chartered Human System Working Group provides oversight for integration and coordination of the risk-based deliverables and requirements for the human system.

This version of the Roadmap was based on three Reference Missions. These Reference Missions, as described in Table 5-1, illustrate some typical parameters used for mission planning purposes and closely predicted the goals of the President's 2004 Space Exploration Vision. Future work will re-examine the Roadmap as necessary with regard to selected mission scenarios as they are further developed and additional mission characteristics are defined. For example, reference missions involving artificial gravity, either as a countermeasure or a design of the transport vehicle itself (i.e. a spinning vehicle), are not addressed here, but may be incorporated in the future. For the purpose of this document, the ISS mission is based on a one-year rotation of the crew. Other durations are not considered here.

Table 5-1: Roadmap Reference Missions (as of July 2003)

Parameters	**Reference Missions**		
	ISS (1-yr)	**Moon (30-d)**	**Mars (30-m)**
Crew Size	2+	4-6	6
Launch Date	NET 2006	NET 2015, NLT 2020	NET 2025-2030
Mission Duration	12 Months	10-44 Days	30 Months
Outbound Transit	2 Days	3-7 Days	4-6 Months
On-Site Duration	12 Months	4-30-days	18 Months
Return Transit	2 Days	3-7 Days	4-6 Months
Communication lag time	0 +	1.3 Seconds+	3-20 Minutes+
Hypogravity	0-G	1/6-G for up to 30 days	1/3-G for up to 18 months
Internal Environment	14.7 psi	TBD	TBD
EVA	0-4 per mission	2-3 week; 4-15/person	2-3/week; 180/person

5.2 Risk Identification

The discipline teams identified the important biomedical, human health, and system performance/efficiency risks for human space flight for each of the Reference Missions. For purposes of the Roadmap, a *risk* is defined as the conditional probability of an adverse event from exposure to the space flight environment; a *risk factor* is defined as a predisposing condition that contributes to an adverse outcome. Intervening at the level of the risk factor can change the outcome (i.e. the likelihood or severity of risk consequences). Attempts were made by the discipline teams to capture the risk statements at a uniform level and in a consistent manner. Greater specificity was to be represented by the research questions associated with each of the risks. The complex and diverse nature of all the risks and issues represented by the human system adapting to space flight makes this a challenging endeavor.

Risks were derived from the deliberations of experts representing the various disciplines involved in Bioastronautics. Fifteen discipline teams are represented in the Roadmap and are organized by five crosscutting areas essential for ensuring the health and safety of the crew:

- Human Health and Countermeasures (HHC)
- Behavioral Health and Performance (BHP)
- Radiation Health (RH)
- Autonomous Medical Care (AMC)
- Advanced Human Support Technology (AHST)

Table 5-2 illustrates the crosscutting areas and the associated disciplines and gives a brief description of each crosscutting area.

Table 5-2: Roadmap Crosscutting Areas and Discipline Teams

Crosscutting Areas	Discipline Teams
Human Health and Countermeasures (HHC): *Focuses on understanding, characterizing, and counteracting the body's adaptation to microgravity, enabling healthy astronauts to accomplish mission objectives and return to normal life following a mission.*	Bone Loss Cardiovascular Alterations Environmental Health Immunology & Infection Skeletal Muscle Alterations Sensory-Motor Adaptation Nutrition
Autonomous Medical Care (AMC): *The capability to provide medical care during a mission with little or no real-time support from Earth. Crew medical officers or other crewmembers provide routine or emergency medical care using available resources. The local resources in an autonomous system augment and support the caregiver. Additionally, part of creating an autonomous medical care system includes preventing or reducing the likelihood of conditions before a mission starts, thus reducing the capabilities and consumables needed in the medical system.*	Clinical Capabilities
Behavioral Health and Performance (BHP): *Focuses on maintaining the psychosocial and psycho-physiological functions of the crew throughout space flight missions and providing an optimal set of countermeasures.*	Behavioral Health & Performance and Space Human Factors (Cognitive)
Radiation Health (RH): *Defines the research strategy and develops risk projection thereby increasing allowable crew time in space, and reducing uncertainty for cancer and other radiation risks.*	Radiation
Advanced Human Support Technologies (AHST): *Focuses on developing efficient, reliable and autonomous technologies and systems to support human habitation in spacecraft and planetary dwellings. These technologies include: food and life support systems, environmental monitoring and*	Advanced Environmental Monitoring & Control Advanced Extravehicular Activity Advanced Food Technology Advanced Life Support Space Human Factors Engineering

control systems, EVA technologies, and human factors solutions through integrated testing in appropriate facilities	

5.2.1 Risk Data Sheets

Risk Data Sheets (RDS) provide the database for the Roadmap and were developed to record all relevant risk identification information (see Appendix A). The information includes risk title, description, risk factors, current and projected countermeasures and other deliverables, the risk rating or assessment for each Reference Mission, risk justification, the associated research and technology questions (R&TQ) and their priorities for each Reference Mission, and important references. Appendix A contains all of the RDS's for all 45 risks, organized by crosscutting area.

5.3 Identification of Research and Technology Questions

The Research and Technology Questions (R&TQ) encompass issues that should be sufficiently addressed to mitigate and retire risks. Discipline teams originally identified these questions by reviewing reports from previous NASA advisory committees and results from NASA's Bioastronautics research program. Each discipline team prioritized the set of R&TQ for each risk, by Reference Mission, based on a "1-5" priority ranking of relative importance[3]. The discipline teams updated the questions during the revision process that resulted in Rev. E, based on instructions from the BSMT designed to ensure consistency and quality in the questions (i.e. that questions are answerable, specific, and measurable). Each team streamlined questions to eliminate redundancies, developed new questions as appropriate, and eliminated existing questions that may have been answered. Question Categories were developed for program assessment purposes. Some categories are specific to a given crosscutting area, while others relate to multiple areas (See Table 5-3).

3 Forward work will include development of additional criteria to assess and prioritize the R&TQ for each of the exploration missions, emphasizing for example, mission impact, temporal priorities, and interdependencies.

Table 5-3: Research & Technology Question Categories

Category	Crosscutting Areas
Countermeasures	Autonomous Medical Care(AMC); Behavioral Health and Performance(BHP); Human Health and Countermeasures(HHC)
Mechanisms	
Medical Diagnosis & Treatment	
Risk Assessment	
Training	
Treatment	Radiation Health(RH)
Prevention (selection and countermeasures)	
Monitoring	
Diagnosis	
Informatics (crosscutting)	
Design Tools	Advanced Human Support Technologies(AHST)
Operations and Training	
Requirements/Specifications	
Technologies	

5.4 Defining Deliverables

Roadmap deliverables are specific products that have been identified as desirable outcomes or solutions to the R&TQ. They have date-specific expectations associated with them in order to meet exploration mission milestones. Some of the research and technology deliverables may be used to develop requirements for the human system, such as countermeasures; others may be used to develop standards or knowledge that informs policy recommendations for crew health and safety.

Table 5-4 lists the different categories of deliverables and some specific examples. Appendix C shows the proposed schedules of deliverables for the five crosscutting areas at a top level.

Table 5-4: Areas to which Roadmap Deliverables Contribute

Category	Definition/Examples
Knowledge Maturation	Reducing uncertainties associated with risk
	Underlying processes/mechanisms
	Modeling
	Risk assessment and characterization
	Example: Reduce uncertainties in radiation measurement
Standards	Fitness for duty criteria
	Flammability standards
	Crew screening and selection criteria (individual, group, psychological, genetic)
	Habitability standards
	Permissible Exposure Limits - radiation, muscle mass and strength, bone loss
	Example: SMACs
Requirements	Health and performance monitoring requirements
	Air monitoring requirements

	Exercise requirements
	Shielding requirements
	Nutritional requirements
	Pharmacological requirements
	Habitability requirements
	Artificial gravity requirements
	Flight Rules
Countermeasures	Exercise protocol
	Pharmacological regimen
	Stress reduction strategies
Human System Assessment/Diagnostic/Treatment Tools	Health and medical status diagnosis and treatment
	Post-landing rehabilitation
	Models
	Performance indicators
	Diagnostic tools to quantify changes
	Example: Automated recording devices to capture, store, and download physiological data
Training and Credentialing	Expert systems
	In-flight operational training
	Ground support training
	Maintenance training
In-flight Protocols	Treatment protocol
	Maintenance protocol
	Example: Capabilities to meet increasing requirement for autonomous medical care
Design Tools	Tools to model complex mission task and productivity
Technologies	Sensors/monitors/instruments
	Improved packaging/design
	Informatics & Communication
	Example: Sensors for noise levels, sleep loss instruments, food systems, pharmaceuticals
Components/Subsystems/Systems	EVA suit
	Water quality sensor suite
	Countermeasures suite
	Waste management system

5.5 Assessing Readiness Levels

Readiness refers to the level of maturity of the countermeasure or technology being developed by a task or project. Two methods are used to determine readiness, one for countermeasures and one for technology deliverables, as shown in Table 5-5. The readiness levels are used for several purposes: to gauge risk mitigation status; to assess progress in developing countermeasures and technologies; to evaluate current program tasks; and to rate risks. Roadmap activities must focus on operational issues and solutions to operational problems to support an outcome-oriented approach. To support that, Bioastronautics research is focusing more on CRL/TRL levels of 4 or greater. Research findings are incorporated into operational procedures through a process defined as the "Transition to Medical Practice Review Process," as issued by the OCHMO. [Note: In the RDS field entitled 'Projected Countermeasures or Mitigations and Other Deliverables', the TRL/CRL specified for each deliverable is the current (FY 2005) level of readiness".]

Table 5-5: Countermeasures Readiness Level (CRL)/Technology Readiness Level (TRL)

<table>
<tr><th>TRL Definition</th><th>TRL/CRL Score</th><th>CRL Definition</th><th colspan="2">CRL Category</th></tr>
<tr><td>Basic principles observed</td><td>1</td><td>Phenomenon observed and reported. Problem defined.</td><td rowspan="3">Basic Research</td><td rowspan="2"></td></tr>
<tr><td>Technology concept and/or application formulated</td><td>2</td><td>Hypothesis formed, preliminary studies to define parameters. Demonstrate feasibility.</td></tr>
<tr><td>Analytical and experimental critical function/proof-of-concept</td><td>3</td><td>Validated hypothesis. Understanding of scientific processes underlying problem.</td><td rowspan="3">Research to Prove Feasibility</td></tr>
<tr><td>Component and/or breadboard validation in lab</td><td>4</td><td>Formulation of countermeasures concept based on understanding of phenomenon.</td><td rowspan="4">Countermeasure Development</td></tr>
<tr><td>Component and/or breadboard in relevant environment</td><td>5</td><td>Proof of concept testing and initial demonstration of feasibility and efficacy.</td></tr>
<tr><td>System/subsystem model or prototype demonstration in relevant environment</td><td>6</td><td>Laboratory/clinical testing of potential countermeasure in subjects to demonstrate efficacy of concept.</td><td></td></tr>
<tr><td>Subsystem prototype in a space environment</td><td>7</td><td>Evaluation with human subjects in controlled laboratory simulating operational space flight environment.</td><td rowspan="2">Countermeasure Demonstration</td></tr>
<tr><td>System completed and flight qualified through demonstration</td><td>8</td><td>Validation with human subjects in actual operational space flight to demonstrate efficacy and operational feasibility.</td><td></td></tr>
<tr><td>System flight proven through mission operations</td><td>9</td><td>Countermeasure fully flight-tested and ready for implementation.</td><td colspan="2">Countermeasure Operations</td></tr>
</table>

6.0 ROADMAP RISKS AND RESEARCH AND TECHNOLOGY QUESTIONS

This section presents summary information for the risks and research and technology questions. The deliberative processes for risk rating identified five overarching issues that are important for defining and reducing risks. These include:

- The need for ground-based integrated testing involving humans and spacecraft systems (environmental life support testing, countermeasure evaluation and validation, and end-to-end testing)
- Actual risks must be operationally based, not research-based
- Key human system requirements (e.g., radiation shielding, habitability standards, etc.) should be incorporated into spacecraft and mission designs early in the process
  - ➢ Designers and bioastronautics experts should work together to optimize the accommodation of the human element
- All Human Health and Performance support hardware (Exercise equipment, environmental monitoring hardware, medical diagnostic and therapeutic equipment) must be designed to assure reliability
- An integrated approach is required to develop efficient engineering solutions for the human support systems that avoid excessive resource costs (i.e. efficient in the sense of the following: low mass, low power consumption, low consumables requirements, high reliability, and low maintenance)

While an informal assessment indicates that progress has been made toward answering some of the questions, a complete formal analysis remains to be done. Future work includes assessing what questions have been sufficiently or partially answered, and how that contributes to mitigating and retiring a risk. In addition, priorities among the questions should continue to be assessed and understood in terms of mission relevance and impact.

Table 6-1: Risks and R&TQ for Each Discipline and Crosscutting Area

Crosscutting Area	**Discipline**	**Total No. Risks**	**Total No. EQs**		
			ISS	**Lunar**	**Mars**
Human Health and Countermeasures	Bone Loss	4	29	29	29
	Cardiovascular Alterations	2	21	21	21
	Environmental Health	1	11	11	11
	Immunology & Infection	3	25	25	25
	Skeletal Muscle Alterations	2	28	28	28
	Sensory-Motor Adaptation	3	42	45	43
	Nutrition	1	12	12	12
	Totals	*16*	*168*	*171*	*169*

Autonomous Medical Care	Clinical Capabilities	7	73	73	75
	Totals	*7*	*73*	*73*	*75*
Behavioral Health and Performance	Behavioral Health & Performance and Space Human Factors (Cognitive)	4	33	33	33
	Totals	*4*	*33*	*33*	*33*
Radiation Health	Radiation	4	41	41	41
	Totals	*4*	*41*	*41*	*41*
Advanced Human Support Technologies	Advanced Environmental Monitoring & Control	5	27	27	27
	Advanced Extravehicular Activity	1	14	14	14
	Advanced Food Technology	1	15	15	15
	Advanced Life Support	5	62	62	62
	Space Human Factors Engineering	2	18	18	18
	Totals	*14*	*136*	*136*	*136*
	Totals	*45*	*451*	*454*	*454*

The total number of risks and R&TQ for each of the three Reference Missions is shown above in Table 6-1. The specific risks and risk descriptions for each of the disciplines are shown below in Tables 6-2 through 6-6, organized by the five crosscutting areas.

Table 6-2: Crosscutting Area: Human Health and Countermeasures (HHC)

Risk No.	Discipline	Risk Title	Risk Description
1	Bone Loss	Accelerated Bone Loss and Fracture Risk	Osteoporosis associated with age-related bone loss may occur at an earlier age due to failure to recover bone lost during space flight.
2	Bone Loss	Impaired Fracture Healing	Bone fractures incurred during and immediately after long duration space flight may require a prolonged period for healing, and the bone may be incompletely restored due to changes in bone metabolism associated with space flight.
3	Bone Loss	Injury to Joints and Intervertebral Structures	The risk of fascia, tendon, and/or ligament overuse, and traumatic injury or joint dysfunction upon return to normal/partial gravity may increase due to prolonged mission duration. Hypogravity changes to intervertebral discs may increase the risk of rupture,

			with attendant back pain, and possible neurological complications.
4	Bone Loss	Renal Stone Formation	The potential for renal stone formation may be increased due to elevated urine calcium concentration associated with bone resorption during exposure to hypogravity and to decreased urine volume during periods of dehydration.
5	Cardiovascular Alterations	Occurrence of Serious Cardiac Dysrhythmias	Serious cardiac dysrhythmias may occur due to prolonged exposure to hypogravity or asymptomatic cardiac disease.
6	Cardiovascular Alterations	Diminished Cardiac and Vascular Function	Diminished cardiac function, orthostatic or postural hypotension, and the impaired ability to perform strenuous tasks on a planetary surface may occur due to prolonged exposure to hypogravity.
7	Environmental Health	Define Acceptable Limits for Contaminants in Air and Water	Crew health and performance may be jeopardized due to the inability to define acceptable limits for contaminants.
8	Immunology & Infection	Immune Dysfunction, Allergies and Autoimmunity	Atopic and autoimmune diseases may occur due to long-term space flight effects on immune-regulatory pathways or on specific immune cells.
9	Immunology & Infection	Interaction of Space flight Factors, Infections and Malignancy	Increased risk of infections or cancers may result from immune dysfunction caused by the interaction of space flight factors.
10	Immunology & Infection	Alterations in Microbes and Host Interactions	Alterations in microbes and host interactions due to exposure to space flight conditions may result in previously innocuous microorganisms endangering the crew and life support systems.
11	Skeletal Muscle Alterations	Reduced Muscle Mass, Strength, and Endurance	Performance of mission related physical activities may be impaired due to loss of muscle mass, strength, and endurance associated with prolonged exposure to hypogravity.
12	Skeletal Muscle Alterations	Increased Susceptibility to Muscle Damage	Risk of injury to skeletal muscle and associated connective tissues may be increased due to remodeling and weakening associated with prolonged exposure to hypogravity.
13	Sensory-Motor Adaptation	Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing	Operational performance may be impaired by spatial disorientation, perceptual illusions, and/or disequilibrium which may occur during and after g-transitions due to maladaptation of the sensory-motor systems to the new gravito-inertial environment.
14	Sensory-Motor Adaptation	Impaired Sensory-Motor	Capability to egress the vehicle in an emergency or to perform post landing tasks may be compromised

		Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation	by impaired movement and coordination caused by long-term exposure to microgravity.
15	Sensory-Motor Adaptation	Motion Sickness	Crew work capacity, vigilance, and motivation may be impaired by motion sickness symptoms occurring during and after g transitions.
16	Nutrition	Inadequate Nutrition	Maintenance of astronaut health depends on a food system that provides all of the required nutrients.

Table 6-3: Crosscutting Area: Autonomous Medical Care (AMC)

Risk No.	Discipline	Risk Title	Risk Description
17	Clinical Capabilities	Monitoring and Prevention	The risk of serious medical events may increase due to inadequate monitoring and prevention capabilities.
18	Clinical Capabilities	Major Illness and Trauma	Lack of capability to treat major illness and injuries increases the risk to crew health and mission.
19	Clinical Capabilities	Pharmacology of Space Medicine Delivery	Diminished drug efficacy due to reduced shelf life and alterations in pharmacodynamics and pharmacokinetics may compromise treatment capabilities.
20	Clinical Capabilities	Ambulatory Care	Impaired performance and increased risk to crew health and mission may occur due to lack of capability to diagnose and treat minor illnesses.
21	Clinical Capabilities	Rehabilitation on Mars	Crew capability to function after landing on Mars may be compromised due to space flight deconditioning and lack of a remote, self-administered, rehabilitation program.
22	Clinical Capabilities	Medical Informatics, Technologies, and Support Systems	Limited communication capability during space flight results in the compromised ability to provide medical care, and may have adverse consequences for crew health.
23	Clinical Capabilities	Medical Skill Training and Maintenance	Inability to perform required medical procedures may result from inadequate crew medical skills or medical training.

Table 6-4: Crosscutting Area: Behavioral Health and Performance (BHP)

Risk No.	Discipline	Risk Title	Risk Description
24	Behavioral Health & Performance and Space Human Factors (Cognitive)	Human Performance Failure Due to Poor Psychosocial Adaptation	Human performance failure may occur due to problems associated with adapting to the space environment, interpersonal relationships, group dynamics, team cohesiveness, and pre-mission preparation.
25	Behavioral Health & Performance and Space Human Factors (Cognitive)	Human Performance Failure Due to Neurobehavioral Problems	Human performance failure may occur due to conditions such as depression, anxiety, or other psychiatric and cognitive problems.
26	Behavioral Health & Performance and Space Human Factors (Cognitive)	Mismatch between Crew Cognitive Capabilities and Task Demands	Human performance failure may occur due to inadequate design of tools, interfaces, tasks, and information support systems. Task saturation may also occur due to compromises in crew health, human factors, and cognitive capabilities.
27	Behavioral Health & Performance and Space Human Factors (Cognitive)	Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems	Human performance failure may occur due to circadian disruption, and acute or chronic degradation of sleep quality and quantity.

Table 6-5: Crosscutting Area: Radiation Health (RH)

Risk No.	Discipline	Risk Title	Risk Description
28	Radiation	Carcinogenesis	Increased cancer morbidity or mortality risk in astronauts may be caused by occupational radiation exposure.
29	Radiation	Acute and Late CNS Risks	Acute and late radiation damage to the central nervous system (CNS) may lead to changes in motor function and behavior, or neurological disorders. This may be caused by occupational radiation exposure or the combined effects of radiation and other space flight factors.
30	Radiation	Chronic and Degenerative Tissue Risks	Radiation exposure may result in degenerative tissue diseases (non-cancer or non-CNS) such as cardiac, circulatory, or digestive diseases, as well as cataracts. This may be caused by occupational radiation exposure or the combined effects of radiation and other space flight factors.
31	Radiation	Acute Radiation Risks	Acute radiation syndromes may occur due to occupational radiation exposure

Table 6-6: Crosscutting Area: Advanced Human Support Technology (AHST)

Risk No.	Discipline	Risk Title	Risk Description
32	Advanced Environmental Monitoring & Control	Monitor Air 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 by automated response equipment, leading to increased hazards to the crew.
33	Advanced Environmental Monitoring & Control	Monitor External Environment	Failure to detect hazards external to the habitat (e.g., dust, fuel contaminants) can lead to lack of remedial action, and poses an increased risk to the crew.
34	Advanced Environmental Monitoring & Control	Monitor Water Quality	Lack of timely information about the build-up of chemicals or microbial growth in the crew water supply, or elsewhere in the water reclamation system, can lead to a delayed response by the crew, or the automated response equipment, and pose a hazard to the crew.
35	Advanced Environmental Monitoring & Control	Monitor Surfaces, Food, and Soil	Lack of timely information, or failure to detect the presence of harmful chemicals or microbial growth on surfaces, food supplies, or soil (required for plant growth) can pose a crew health hazard.
36	Advanced Environmental Monitoring & Control	Provide Integrated Autonomous Control of Life Support Systems	Lack of stable, reliable, efficient process control for the life support system can pose a hazard to crew health or create an excessive crew workload.
37	Advanced Extravehicular Activity	Provide Space Suits and Portable Life Support Systems	EVA performance and crew health may be compromised by inadequate EVA systems.
38	Advanced Food Technology	Maintain Food Quantity and Quality	Crew nutritional requirements may not be met and crew health and performance compromised due to inadequate food acceptability, preparation, processing, and storage systems.
39	Advanced Life Support	Maintain Acceptable Atmosphere	Crew health may be compromised due to inability of currently available technology to monitor and control spacecraft atmosphere. Risk may be mitigated by development of new technologies that will be integrated into the life support systems.

40	Advanced Life Support	Maintain Thermal Balance in Habitable Areas	Crew health may be compromised due to inability of currently available technology to provide crew module thermal control. Risk may be further mitigated by development of new technologies that will be integrated into the thermal control system.
41	Advanced Life Support	Manage Waste	Crew health may be compromised due to inability of currently available technology to adequately process solid wastes reliably with minimum power, mass, volume. Inadequate waste management can also lead to contamination of planetary surfaces.
42	Advanced Life Support	Provide and Maintain Bioregenerative Life Support Systems	Sustaining crew health and performance may be compromised by lack of bioregenerative systems.
43	Advanced Life Support	Provide and Recover Potable Water	Crew health may be compromised due to inability of currently available technology to adequately provide and recover potable water.
44	Space Human Factors Engineering	Mismatch Between Crew Physical Capabilities and Task Demands	Human performance failure may occur due to human factors inadequacies in the physical work environments (e.g., workplaces, equipment, protective clothing, tools and tasks).
45	Space Human Factors Engineering	Poorly Integrated Ground, Crew, and Automation Functions	Mission performance failure may occur without adequate operational concepts, design requirements, and design tools for integration of multiple factors that affect mission performance, such as ground-crew interaction, communication time, and level of automation.

7.0 RISK ASSESSMENT AND RATING RESULTS

This section describes the methods and results for rating the Roadmap risks. It includes the definition of the criteria used to rate the two general types of risks: human health risks and system performance/efficiency risks. The ratings for the human health risks were derived from an analysis of the likelihood of its occurrence, the severity of its consequence should it occur, and the risk mitigation status. The system performance risks were assessed in terms of improved efficiency. These results are summarized and the conclusions are discussed.

7.1 Risk Assessment and Rating

The process of analysis and deliberations used to assess and rate the relative importance of the identified risks incorporated several steps as described below and shown in Table 7-1.

(1) Discipline experts provided the initial risk assessment information and analysis.

(2) The BSMT utilized that data as input for conducting the rating of relative risk priority using the red/yellow/green, 5X5 classification.

(3) Representatives from the OCHMO along with other representatives of health policy and management participated in the risk rating process. The criteria for rating the Roadmap risks followed a workshop held to analyze the requirements for human subject participation in the Roadmap risk reduction strategy. Those two criteria included: likelihood of the risk to compromise a mission to Mars, and the need for the related research to be conducted on ISS.

(4) A workshop determined the number of human subjects required to conduct exploration research. The workshop included approximately 60 representatives from the Bioastronautics research community. The set of 50 risks from the Roadmap were assessed using various criteria (e.g., current level of risk mitigation status, types of experiments required to reduce risk, human or nonhuman research requirements, ground and flight requirements, and long or short duration requirements) to determine the number of subjects required for risk reduction purposes (NASA Workshop Report, May 12-13, 2004).

(5) Representatives from the Astronaut Office, the Space Medicine and Health Care Office, and the BSMT participated in a workshop to derive a consensus rating of the Roadmap risks. One conclusion of that workshop was the determination to use a different rating scheme (other than the red/yellow/green tool) to assess the relative importance among the risks. There were several changes made to the risks and questions and three overarching issues were identified (need for functioning, reliable medical support hardware, incorporation of medical requirements and issues into vehicle design and architecture, and the Roadmap risks and questions must be operationally focused). In addition, related Roadmap issues were discussed (e.g., the time required for research, the interface between research and operations, and the peer review process).

(6) The last steps involved deliberations among the BSMT and a sub-group of that, at several Roadmap workshops. The results of all of the previous workshops were utilitzed during those deliberation as well as input from the public. This process developed a consensus rating of the 45 risks, using a 1/2/3 categorization indicating the relative importance of the risks. Results from all of the deliberative processes identified five overarching issues as previously discussed in Section 6.0.

Table 7-1: Input and Workshops for Risk Rating Analysis and Deliberations

Risk Rating Input and Workshops	**Date**
Discipline Teams	Jan – Feb 2004
BSMT	Mar – April 2004
Animal Workshop – research community	April 2004
Human Subjects Workshop – research community	May 2004
Public Comment Query	April – June, 2004
Astronaut Office, Flight Surgeons, BSMT	May 2004
Health and Medical Policy	June 2004
BSMT	August 2004

7.2 Risk Rating Results

The 45 Roadmap risks are considered to be the most important to the human system for long-duration space flight, whether in LEO or on exploration missions. The risk-rating criteria adopted by the BSMT were used to determine the relative importance of each risk with respect to the Reference Missions. As shown in Table 7-2, the criteria were based on a qualitative assessment derived from an understanding of the risk's likelihood, severity of impact, and mitigation status. Two sets of criteria were used: one for the human health-related risks, a second, for the system performance/efficiency-related risks. Since the outcome illustrates relative importance, the tool aids both risk communication and decision-making processes, guiding research planning and resource allocation.

It is also important to note that the risk rating was not an attempt to assess flight readiness. The Priority 1/2/3 categories used for the various ratings were applied consistently across all 45 risks for each of the three Reference Missions.

The categories for designating the priority status of each risk are shown in Table 7-2. Table 7-3 shows results for rating the human health risks; Tables 7-4 shows the results for the system performance and efficiency risks.

Table 7-2: Risk Rating Categories and Priority Definitions

Risk Rating Priority	Human Health Risks	System Performance/Efficiency Risks
1	Risk of serious adverse health or performance consequences, and there is no mitigation strategy that has been validated in space or demonstrated on Earth.	Considerable potential for improvement in mitigation efficiency in many areas; proposed missions may be infeasible without improvements.
2	Risk of serious health or performance consequences, and there is no mitigation strategy that has been validated in space.	Considerable potential for improvement in mitigation efficiency in a few areas.
3	Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space.	Minimum potential or limited need for improvement in mitigation efficiency.

Acronyms for Human Health Risks (See Table 7-3 below)

AMC	Autonomous Medical Care
BHP	Behavioral Health and Performance
BHP\SHF	Behavioral Health & Performance and Space Human Factors (Cognitive)
Bone	Bone Loss
Cardio	Cardiovascular Alterations
Clinical	Clinical Capabilities
EH	Environmental Health
HHC	Human Health and Countermeasures
II	Immunology & Infection
Muscle	Skeletal Muscle Alterations
RH	Radiation Health
SM	Sensory-Motor Adaptation

Acronyms for System Performance/Efficiency Risks (See Table 7-4 below)

AEMC	Advanced Environmental Monitoring & Control
AEVA	Advanced Extravehicular Activity
AFT	Advanced Food Technology
AHST	Advanced Human Support Technologies
ALS	Advanced Life Support
SHFE	Space Human Factors Engineering

Table 7-3: Risk Rating Results for Human Health Risks

Risk Number	CC Area	Discipline	Risk Title	ISS Priority (1-yr)	Moon Priority (30-d)	Mars Priority (30-m)
1	HHC	Bone	Accelerated Bone Loss and Fracture Risk	2	3	2
2	HHC	Bone	Impaired Fracture Healing	3	3	2
3	HHC	Bone	Injury to Joints and Intervertebral Structures	3	2	2
4	HHC	Bone	Renal Stone Formation	3	3	3
5	HHC	Cardio	Occurrence of Serious Cardiac Dysrhythmias	2	2	2
6	HHC	Cardio	Diminished Cardiac and Vascular Function	2	2	2
7	HHC	EH	Define Acceptable Limits for Contaminants in Air and Water	3	2	1
8	HHC	II	Immune Dysfunction, Allergies and Autoimmunity	2	2	2
9	HHC	II	Interaction of Space flight Factors, Infections and Malignancy	2	3	2
10	HHC	II	Alterations in Microbes and Host Interactions	3	3	2
11	HHC	Muscle	Reduced Muscle Mass, Strength, and Endurance	2	3	2
12	HHC	Muscle	Increased Susceptibility to Muscle Damage	3	3	2
13	HHC	SM	Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing	2	2	2
14	HHC	SM	Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation	2	2	2
15	HHC	SM	Motion Sickness	3	3	3
16	HHC	Nutrition	Inadequate Nutrition	3	3	2
17	AMC	Clinical	Monitoring and Prevention	2	2	1
18	AMC	Clinical	Major Illness and Trauma	2	1	1
19	AMC	Clinical	Pharmacology of Space Medicine Delivery	2	2	1
20	AMC	Clinical	Ambulatory Care	3	3	2
21	AMC	Clinical	Rehabilitation on Mars	N/A	N/A	1
22	AMC	Clinical	Medical Informatics, Technologies, and Support Systems	3	2	1
23	AMC	Clinical	Medical Skill Training and Maintenance	3	2	1
24	BHP	BHP\SHF	Human Performance Failure Due to Poor Psychosocial Adaptation	1	2	1
25	BHP	BHP\SHF	Human Performance Failure Due to Neurobehavioral Problems	1	2	1
26	BHP	BHP\SHF	Mismatch between Crew Cognitive Capabilities and Task Demands	2	2	1
27	BHP	BHP\SHF	Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems	3	3	2
28	RH	Radiation	Carcinogenesis	2	1	1
29	RH	Radiation	Acute and Late CNS Risks	2	2	1
30	RH	Radiation	Chronic and Degenerative Tissue Risks	2	2	1
31	RH	Radiation	Acute Radiation Risks	3	2	1

Table 7-4: Risk Rating Results for System Performance/Efficiency Risks

Risk Number	CC Area	Discipline	Risk Title	ISS Priority (1-yr)	Moon Priority (30-d)	Mars Priority (30-m)
32	AHST	AEMC	Monitor Air Quality	2	1	1
33	AHST	AEMC	Monitor External Environment	2	1	1
34	AHST	AEMC	Monitor Water Quality	2	1	1
35	AHST	AEMC	Monitor Surfaces, Food, and Soil	2	1	1
36	AHST	AEMC	Provide Integrated Autonomous Control of Life Support Systems	3	2	1
37	AHST	AEVA	Provide Space Suits and Portable Life Support Systems	3	2	1
38	AHST	AFT	Maintain Food Quantity and Quality	2	3	1
39	AHST	ALS	Maintain Acceptable Atmosphere	3	2	1
40	AHST	ALS	Maintain Thermal Balance in Habitable Areas	3	2	1
41	AHST	ALS	Manage Waste	3	2	1
42	AHST	ALS	Provide and Maintain Bioregenerative Life Support Systems	3	2	1
43	AHST	ALS	Provide and Recover Potable Water	3	2	1
44	AHST	SHFE	Mismatch Between Crew Physical Capabilities and Task Demands	2	2	1
45	AHST	SHFE	Poorly Integrated Ground, Crew, and Automation Functions	2	2	1

8.0 RISK ASSESSMENT AND MANAGEMENT

Assessment and management of the Roadmap research and risks depends on development, selection and implementation of the right mitigation strategies. Those strategies are the result of an approach based on integration, project management, and configuration control.

8.1 Roadmap Integration and Interaction

An integrated Roadmap approach must be used to achieve effective and efficient risk reduction solutions. An integrated approach includes interdisciplinary teams composed of research, engineering, and operational perspectives in the definition and assessment of progress made toward risk reduction. This point is further emphasized by one of the conclusions from the deliberative process specifically, the need to improve the interface between research and operations in such areas as, the transition from research to operations, research facilitating operations, and hardware development. Delivering an integrated, validated suite of technologies, standards, and operations concepts for future reference missions will reduce the programmatic risk of the human system.

The research strategy must also reflect the integrated nature inherent in the risks and questions. There are considerable interdependencies and interactions among the risks, risk factors, and research questions. (The risks and questions are listed in the Risk Data Sheets in Appendix A.) The research strategy must also incorporate the development and application of a more refined set of decision criteria that augments the current risk priorities and establishes relevant “weighting” among the entire set of risks with regard to those criteria. Such criteria will include for example: mission impact and relevance, temporal priorities (including long lead time), interdependencies, benefit/cost analysis, and practicality/feasibility.

Another aspect of integration is the inclusion of the engineering, technology-focused efforts represented by the Life Support and Habitation programs. These activities include: Advanced Food Technology (AFT), Advanced Life Support (ALS), Advanced Environmental Monitoring and Control (AEMC), Space Human Factors Engineering (SHFE) and Advanced Extravehicular Activities (AEVA) systems. All of these are important components of the system ensuring that the crew can live and work in space vehicles or surface dwellings.

Integration and management of the integration also exists at the level of ground and flight testing. Capabilities such as the Advanced Integration Matrix (AIM) will provide the means to study and optimize system-level interfaces and interactions and help ensure that the technologies and countermeasures for the human system meet the needs of the program for the exploration missions. In addition, ground studies should be used when possible because of resource constraints associated with in-flight testing and validation. The Roadmap strategy for the human system risks utilizes space flight for those mitigation solutions most requiring it.

8.2 Using a Project Approach

The Roadmap uses a project management approach to achieve its objectives. Project management imposes discipline on research activities and focuses on schedules and deliverables while maintaining quality and cost control. Project management teams foster valued integration and commitment from the participating experts and stakeholders. Project management teams also contribute to the development and use of effective metrics to assess current status and measure progress in reducing risk and answering the R&TQ.

9.0 FORWARD WORK

It is the nature of the Roadmap to continue to evolve. For example, risk information will continue to be modified and updated, as research results are known and implemented Forward work includes:

- Development of a Roadmap implementation plan
- Reestablishment of the BRCP
- Identification of the deliverables for each of the exploration missions
- Continued development of risk assessment and quantification tools, including risk uncertainties, level of evidence, temporal priorities, as well as assessment of overall relative risk
- Development of program evaluation tools and metrics to assess progress made toward risk reduction for the human system and to evaluate the overall success of the activities related to Bioastronautics research
- Recommendations for development of acceptable exposure limits for crew health and performance, and operating bands for life support and habitation elements
- Re-examination of questions and their priorities in terms of mission impact as those missions are further defined
- Applying the risk and question priorities to research solicitation and selection and the appropriate allocation of resources
- Assessment of the confounding effects of risks upon risks, such as additive or cascading risk manifestations

9.1 Benefit/Cost Analysis

The prioritization risks and the selection of effective countermeasures and efficient risk mitigation strategies are closely tied to exposure limits and acceptable levels of risk. Benefit/cost analysis allows balancing of resources along with potential improvements in risk reduction or mitigation efficiencies to avoid investments that are of marginal value. Prioritization may also represent the need for improvement in a given countermeasure or technology. For example, a serious health risk may already be adequately addressed with a low-tech countermeasure. Although there is room for improvement in the countermeasure technically, it adequately controls the risk as is, and may therefore not require resources.

9.2 Metrics

Effective measures of success must start with a clear definition of the goal. In the technology areas, metrics such as mass, power, volume and self-sufficiency are already available and are being used in project planning and management. Measurable targets such as operating bands and exposure limits will be developed and, after appropriate review, may be used as metrics to assess the effectiveness of space flight countermeasures. Project teams and management must use these defined measures to assess and communicate progress. Measures of outcome and progress should address exit criteria for the risks as well as their associated questions and be reported to and reviewed by the HSWG.

10.0 CONCLUSIONS

The following conclusions were derived from the recent Roadmap refinement activity and discussions:

1. Given the time constraints, the Roadmap activities must focus on operational issues, and solutions to operational problems, to support an outcome-oriented approach.

2. High priority health and medical issues for a mission to Mars include: (a) maintaining behavioral health and psychosocial functioning; (b) providing radiation protection; (c) addressing the requirements for AMC capabilities; (d) minimizing bone loss; (e) maintaining sensory-motor capability to perform tasks after landing; (f) ensuring adequate nutrition; (g) monitoring and controlling environmental contaminants; and, (h) providing efficient and reliable health and medical support hardware. For a lunar mission the health and medical issues are: (a) development of environmental life support and habitation technologies; (b) providing capabilities for remote medical care for major illness and trauma; and (c) providing adequate radiation protection.

3. The identified set of risks includes some that have been well documented and proven and others that have not been documented. Further quantification of risks, where appropriate, is an important priority. For example, in the near term it is important to determine whether or not serious cardiac dysrhythmia is a risk associated with prolonged space flight.

4. While a one-year stay on the ISS presents a generally lower risk than the other two missions, the ISS is an important platform for reducing the risks for Moon and Mars missions.

5. It is imperative that a new paradigm be adopted to accomplish the objectives of the Roadmap that further integrates flight and ground activities and optimizes flight resources as it emphasizes the human system. The Roadmap will meet its goals and objectives, and effectively manage its risks by using a project management approach.

6. Effective measures of success in identifying and assessing risk must be defined with a clear goal, and project teams and management must use these defined measures to assess and communicate progress.

7. Participation of the key stakeholders in the deliberation process is integral for risk identification and assessment. It is essential that astronauts and flight surgeons participate in the continued evolution of the Roadmap.

8. Communication, integration, and coordination among intramural and extramural biomedical researchers, technology developers, flight surgeons, astronauts and NASA management and the field centers are essential for the success of the Roadmap.

9. It is the recommendation of the BSMT that a strategy be developed to address the five overarching issues for the human system.

In conclusion, Bioastronautics has evolved over the past eight years as a strategy for guiding research and technology development and helping inform policy and operations that are based on risk assessment and risk reduction solutions that ensure the health, safety, and performance of the human system in exploration missions. It is the intent to continue this process with a focus toward making possible the more complex and challenging operations for humans living and working in more distant and dangerous space and planetary environments.

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APPENDIX A: RISK DATA SHEETS

Risk Title: Accelerated Bone Loss and Fracture Risk

<table>
<tr><td>Crosscutting Area :</td><td>Human Health and Countermeasures (HHC)</td></tr>
<tr><td>Discipline :</td><td>Bone Loss</td></tr>
<tr><td>Risk Number :</td><td>1</td></tr>
<tr><td>Risk Description :</td><td>Osteoporosis associated with age-related bone loss may occur at an earlier age due to failure to recover bone lost during space flight.</td></tr>
<tr><td>Context / Risk Factors :</td><td>This risk may be influenced by age, baseline bone mass density (BMD), gender, nutrition, or muscle loss.</td></tr>
<tr><td>Justification / Rationale :</td><td>Crewmembers lose bone during long-duration space flight, especially in weight bearing bones.Calcium and bone metabolism are altered, and failure to recover lost bone (mission- and age related), can lead to increased risk of fractures at a younger age. ISS crewmembers will be affected to varying degrees. Mitigation strategies are under investigation for ISS missions. Bone loss is not considered a significant problem on a 30-day mission to the Moon. Exploration (Mars) crews will be affected to varying degrees.</td></tr>
<tr><td>Risk Rating :</td><td>ISS: Priority 2
Lunar: Priority 3
Mars: Priority 2</td></tr>
<tr><td>Current Countermeasures :</td><td>• Nutrition
• Exercise (resistive and aerobic)
• Crew Screening and preparation</td></tr>
<tr><td>Projected Countermeasures or Mitigations & other Deliverables:</td><td>• Biophysical modalities [CRL 5]
• Crew Screening [CRL 1]
• Exercise and fitness regimens [CRL 6-7]
• Hormone replacement therapy [CRL 1]
• Nutrition [CRL 4]
• Pharmacological (including bisphosphonates) [CRL 7]
• Rehabilitation strategies [CRL 3]
• Spacesuit design [CRL 1]
• Artificial gravity</td></tr>
<tr><td>Research & Technology Questions [With Mission Priority]:</td><td>
<table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td>1a</td><td>What is the relative risk of sustaining a traumatic and/or stress fracture for a given decrement in bone mineral density, or alteration in bone geometry, in an astronaut-equivalent population who are physically active? [ISS 3, Lunar 5, Mars 1]</td></tr>
<tr><td>1b</td><td>Will a period of rapid bone loss in hypogravity be followed by a slower rate of loss approaching a basal bone mineral density (BMD)? What are the estimated site-specific fracture risks as one approaches basal BMD? [ISS 2, Lunar 5, Mars 1]</td></tr>
<tr><td>1c</td><td>Is there an additive or synergistic effect of gonadal hormone deficiency in men or women on bone loss during prolonged exposure to hypogravity? [ISS 1, Lunar 5, Mars 5]</td></tr>
<tr><td>1d</td><td>What biophysical modalities, nutritional modifications, and pharmacological agents (alone or in combination) will most effectively minimize the decrease in bone mass due to extended hypogravity exposure? [ISS 1, Lunar 5, Mars 1]</td></tr>
<tr><td>1e</td><td>What are the specifics of the optimal exercise regimen with regard to mode, duration, intensity and frequency, to be followed during exposure to hypogravity so as to minimize decreases in bone mass? Is impact loading an essential element and, if so, how can it be produced in hypogravity? [ISS 1, Lunar 3, Mars 1]</td></tr>
</table>
</td></tr>
</table>

1f	What combination of exercise, biophysical modalities, nutritional modifications, and/or pharmacological agent(s) is most effective, efficient (minimal crew time), and safe in preventing bone loss during exposure to hypogravity? **[ISS 1, Lunar 5, Mars 1]**
1g	What are the important predictors for estimating site-specific bone loss and fracture risk during hypogravity exposure, including, but not limited to ethnicity, gender, genetics, age, baseline bone density and geometry, nutritional status, fitness level and prior microgravity exposure? **[ISS 1, Lunar 5, Mars 1]**
1h	Does the hypogravity environment change the nutritional requirements for optimal bone health? **[ISS 3, Lunar 3, Mars 2]**
1i	What diagnostic tools can be utilized during multi-year missions to monitor and quantify changes in bone mass and bone strength? **[ISS 2, Lunar 5, Mars 1]**
1j	What systemic adaptations to hypogravity are important contributory factors to bone loss, evaluations of which are essential for effective countermeasure development (e.g., fluid shifts, altered blood flow, immune system adaptations)? **[ISS 3, Lunar 5, Mars 2]**
1k	Are hypogravity-induced changes in bone density, geometry, and architecture reversible upon encountering partial gravity exposure, or on return to full gravity (1-G)? **[ISS 1, Lunar 5, Mars 1]**
1l	What regimen (exercise, pharmacological, nutritional, or biomechanical including impact loading or artificial gravity exposure) will most effectively hasten restoration of bone mass and/or bone strength (geometry and architecture) to pre-flight values in returning crewmembers? **[ISS 2, Lunar 5, Mars 2]**

Related Risks :

Bone Loss
Impaired Fracture Healing
Injury to Joints and Intervertebral Structures
Renal Stone Formation
Cardiovascular Alterations
Diminished Cardiac and Vascular Function
Immunology & Infection
Immune Dysfunction, Allergies and Autoimmunity
Skeletal Muscle Alterations
Reduced Muscle Mass, Strength, and Endurance
Sensory-Motor Adaptation
Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing
Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation
Nutrition
Inadequate Nutrition
Clinical Capabilities
Monitoring and Prevention
Major Illness and Trauma
Pharmacology of Space Medicine Delivery
Rehabilitation on Mars

Important References :

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http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12959131

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Risk Title: Impaired Fracture Healing

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Bone Loss
Risk Number :	2
Risk Description :	Bone fractures incurred during and immediately after long duration space flight may require a prolonged period for healing, and the bone may be incompletely restored due to changes in bone metabolism associated with space flight.
Context / Risk Factors :	Space flight associated bone loss may increase the risk of traumatic and stress fractures. Inflight risk of injury should be minimized through design of hardware and procedures. Risks may vary between individuals.
Justification / Rationale :	Bone loss associated with space flight may result in additional risk of fracture. Threat to crew health and mission will depend on fracture site, severity and treatment options available. Risk of fracture on ISS is considered extremely low. Risk of fracture on a Lunar mission is low. For a Mars Mission, there is a risk of serious health or performance consequences may be greater because of lack of return capability.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 3 **Mars:** Priority 2
Current Countermeasures :	• Minimize bone loss to lessen fracture risk • Rehabilitation procedures • Crew return capability • Hardware design and procedures to reduce the likelihood of injury

Projected Countermeasures or Mitigations & other Deliverables:

- Biomechanical and pharmacological measures to promote more rapid healing [CRL 5]
- Ultrasound and electrical stimulation [CRL 2] [Lunar] [Mars]
- Minimize bone loss
- Development of treatment options [Lunar] [Mars]

Research & Technology Questions [With Mission Priority]:

No.	Question
2a	Is the rate of fracture healing and the integrity of the healed fracture altered under hypogravity or unloaded conditions? **[ISS 1, Lunar 1, Mars 1]**
2b	Are there site-specific differences or differences in healing diaphyseal bone versus metaphyseal bone under microgravity or partial-gravity conditions? **[ISS 3, Lunar 3, Mars 3]**
2c	Which cellular and biochemical changes in bone cell biology alter fracture healing under microgravity conditions? **[ISS 4, Lunar 4, Mars 4]**
2d	Does the presence of microgravity-induced alteration in bone remodeling and/or osteoporosis affect fracture callus remodeling? **[ISS 2, Lunar 2, Mars 2]**
2e	How do changes in skeletal muscle-bone interactions during space flight contribute to altered fracture healing in microgravity? **[ISS 4, Lunar 4, Mars 4]**
2f	Do biophysical modalities play a role in improving fracture healing in a microgravity environment? **[ISS 2, Lunar 2, Mars 2]**
2g	Do biophysical modalities play a role in improving fracture healing in the presence of bone loss in a microgravity environment? **[ISS 2, Lunar 2, Mars 2]**
2h	Are there anabolic agents, growth factors, or cytokines that will speed fracture repair during microgravity in combination with active bone loss due to unloading? **[ISS 1, Lunar 1, Mars 1]**
2i	What technologies will be used to diagnose fractures of the axial and appendicular skeleton in a space environment? **[ISS 1, Lunar 1, Mars 1]**
2j	Will different technologies be needed to treat either open or closed fractures in a space environment? **[ISS 1, Lunar 1, Mars 1]**

Related Risks :

Bone Loss
Accelerated Bone Loss and Fracture Risk
Injury to Joints and Intervertebral Structures
Renal Stone Formation
Immunology & Infection
Immune Dysfunction, Allergies and Autoimmunity
Skeletal Muscle Alterations
Reduced Muscle Mass, Strength, and Endurance
Sensory-Motor Adaptation
Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing
Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation
Clinical Capabilities
Monitoring and Prevention
Major Illness and Trauma
Pharmacology of Space Medicine Delivery

Important References :	Durnova GN, Burkovskaia TE, Vorotnikova EV, Kaplanskii AS, Arustamov OV. [The effect of weightlessness on fracture healing of rats flown on the biosatellite Cosmos-2044]. Kosm Biol Aviakosm Med. 1991 Sep-Oct;25(5):29-33. Russian. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=8577136 Kaplansky AS, Durnova GN, Burkovskaya TE, Vorotnikova EV. The effect of microgravity on bone fracture healing in rats flown on Cosmos-2044. Physiologist. 1991 Feb;34(1 Suppl):S196-9. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=2047441 Kirchen ME, O'Connor KM, Gruber HE, Sweeney JR, Fras IA, Stover SJ, Sarmiento A, Marshall GJ. Effects of microgravity on bone healing in a rat fibular osteotomy model. Clin Orthop. 1995 Sep;(318):231-42. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=7671522

Risk Title: Injury to Joints and Intervertebral Structures

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Bone Loss
Risk Number :	3
Risk Description :	The risk of fascia, tendon, and/or ligament overuse, and traumatic injury or joint dysfunction upon return to normal/partial gravity may increase due to prolonged mission duration. Hypogravity changes to intervertebral discs may increase the risk of rupture, with attendant back pain, and possible neurological complications.
Context / Risk Factors :	This risk may be influenced by age, loss of muscle strength, state of fitness and conditioning, prior history of injuries, or task related impact on joints and intervertebral structures.
Justification / Rationale :	Hypogravity-induced changes to intervertebral disks and ligaments may increase risk of rupture and/or injury, with attendant back pain, and possible neurological complications. This risk is most significant for a Mars mission.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 2 **Mars:** Priority 2
Current Countermeasures :	• Musculoskeletal Fitness • Post-injury and Post-flight Rehabilitation • Work injury avoidance patterns and design of equipment and tasks to reduce likelihood of injury • Training
Projected Countermeasures or Mitigations & other Deliverables:	• Improved fitness and conditioning regimens
Research & Technology Questions [With Mission Priority]:	

No.	Question
3a	What is the cause of the back pain commonly experienced by crewmembers upon return to 1-G? **[ISS 2, Lunar 3, Mars 2]**
3b	Is damage to joint structure, intervertebral discs, or ligaments incurred during or following hypogravity exposure? **[ISS 2, Lunar 3, Mars 1]**
3c	What countermeasures will protect joint and intervertebral soft tissues (e.g. discs and ligaments) from microgravity or partial gravity-related damage? **[ISS 2, Lunar 2, Mars 1]**
3d	What rehabilitative measures will hasten recovery of soft tissue damage in a partial gravity environments, or upon return to Earth's gravity? **[ISS 2, Lunar 2, Mars 1]**

Related Risks :	**Bone Loss** Accelerated Bone Loss and Fracture Risk Impaired Fracture Healing Renal Stone Formation **Skeletal Muscle Alterations** Reduced Muscle Mass, Strength, and Endurance Increased Susceptibility to Muscle Damage **Sensory-Motor Adaptation** Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation **Clinical Capabilities** Monitoring and Prevention Major Illness and Trauma
Important References :	Foldes I, Kern M, Szilagyi T, Oganov VS. Histology and histochemistry of intervertebral discs of rats participated in space flight. Acta Biol Hung. 1996;47(1-4):145-56. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=9123987 Foldes I, Szilagyi T, Rapcsak M, Velkey V, Oganov VS. Changes of lumbar vertebrae after Cosmos-1887 space flight. Physiologist. 1991 Feb;34(1 Suppl):S57-8. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=2047467 Hutton WC, Malko JA, Fajman WA. Lumbar disc volume measured by MRI: effects of bed rest, horizontal exercise, and vertical loading. Aviat Space Environ Med. 2003 Jan;74(1):73-8. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12546302 LeBlanc AD, Evans HJ, Schneider VS, Wendt RE 3rd, Hedrick TD. Changes in intervertebral disc cross-sectional area with bed rest and space flight. Spine. 1994 Apr 1;19(7):812-7. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=8202800 Maynard JA. The effects of space flight on the composition of the intervertebral disc. Iowa Orthop J. 1994;14:125-33. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=7719767 Oganov VS, Cann C, Rakhmanov AS, Ternovoi SK. [Study of the musculoskeletal system of the spine in humans after long-term space flights by the method of computerized tomography] Kosm Biol Aviakosm Med. 1990 Jul-Aug;24(4):20-1. Russian. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=2214660 Pedrini-Mille A, Maynard JA, Durnova GN, Kaplansky AS, Pedrini VA, Chung CB, Fedler-Troester J. Effects of microgravity on the composition of the intervertebral disk. Appl Physiol. 1992 Aug;73(2 Suppl):26S-32S http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=1526953

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Risk Title: Renal Stone Formation

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Bone Loss
Risk Number :	4
Risk Description :	The potential for renal stone formation may be increased due to elevated urine calcium concentration associated with bone resorption during exposure to hypogravity and to decreased urine volume during periods of dehydration.
Context / Risk Factors :	This risk may be influenced by environmental factors affecting mineral/fluid status, individual propensity for urine calcium oxalate solubility patterns and stone formation.
Justification / Rationale :	Space flight is associated with changes in urine chemistry (decreased urinary pH and citrate and increased urinary calcium and phosphate) and composition (increased calcium oxalate and brushite saturation, and increased concentration of undissociated uric acid) which likely contribute to the increased renal stone risk observed during and after space flight. Mitigation strategies (potassium citrate) are currently under investigation.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 3 **Mars:** Priority 3
Current Countermeasures :	• Good state of hydration • Nutritional counseling
Projected Countermeasures or Mitigations & other Deliverables:	• Nutrition [CRL 4] • Pharmacological agents (e.g., Potassium or Magnesium Citrate, bisphosphonates) [CRL 4-8] • Urine solubility testing in flight
Research & Technology Questions [With Mission Priority]:	(see table below)
Related Risks :	(see table below)

Research & Technology Questions [With Mission Priority]:

No.	Question
4a	What diagnostic measures permit detection of renal calcification during extended-duration space flight? **[ISS 4, Lunar 1, Mars 1]**
4b	What nutritional and/or pharmacological countermeasures adequately minimize risk of stone formation in-flight and upon return to 1-G? **[ISS 3, Lunar 2, Mars 2]**
4c	What is the time course of increased risk for renal stone formation abating upon return to 1-G? **[ISS 3, Lunar 3, Mars 2]**

Related Risks :

Bone Loss
Accelerated Bone Loss and Fracture Risk
Impaired Fracture Healing
Injury to Joints and Intervertebral Structures
Cardiovascular Alterations
Occurrence of Serious Cardiac Dysrhythmias
Nutrition
Inadequate Nutrition
Clinical Capabilities
Monitoring and Prevention

	Major Illness and Trauma Pharmacology of Space Medicine Delivery
Important References :	Pak CY, Hill K, Cintron NM, Huntoon C. Assessing applicants to the NASA flight program for their renal stone-forming potential. Aviat Space Environ Med. 1989 Feb;60(2):157-61. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=2930428 Whitson PA, Pietrzyk RA, Morukov BV, Sams CF. The risk of renal stone formation during and after long duration space flight. Nephron. 2001 Nov;89(3):264-70. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11598387 Whitson PA, Pietrzyk RA, Pak CY, Cintron NM. Alterations in renal stone risk factors after space flight. J Urol. 1993 Sep;150(3):803-7. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=8345588 Whitson PA, Pietrzyk RA, Pak CY. Renal stone risk assessment during Space Shuttle flights. J Urol. 1997 Dec;158(6):2305-10. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=9366381 Whitson PA, Pietrzyk RA, Sams CF. Space flight and the risk of renal stones. J Gravit Physiol. 1999 Jul;6(1):P87-8. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11543039 Whitson PA, Pietrzyk RA, Sams CF. Urine volume and its effects on renal stone risk in astronauts. Aviat Space Environ Med. 2001 Apr;72(4):368-72. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11318017 Zerwekh JE. Nutrition and renal stone disease in space. Nutrition. 2002 Oct;18 (10):857-63. Review. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12361779

Risk Title: Occurrence of Serious Cardiac Dysrhythmias

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Cardiovascular Alterations
Risk Number :	5
Risk Description :	Serious cardiac dysrhythmias may occur due to prolonged exposure to hypogravity or asymptomatic cardiac disease.
Context / Risk Factors :	Other physiological changes, such as altered neural and hormonal regulation, diminished cardiac mass and cardiac remodeling, and fluid and electrolyte alterations, may affect occurence of dysrhythmias. Flight duration, gender, and pre-existing cardiovascular disease are also risk factors.
Justification / Rationale :	Cardiac rhythm disturbances have been observed on several occasions during space flight but the occurrence of space flight induced arrhythmias has not been documented. Recent flight and ground -based data demonstrate alterations in cardiac electrical activity, which may indicate altered cardiac electrical stability. If space flight increases the risk of serious cardiac dysrhythmias this could lead to syncope and/or death posing risk both to crewmembers and to the mission.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 2 **Mars:** Priority 2

<table>
<tr><td>Current Countermeasures :</td><td>Resuscitation equipment, including onboard defibrillator
Crew medical screening
Onboard monitoring</td></tr>
<tr><td>Projected Countermeasures or Mitigations & other Deliverables:</td><td>Electrical cardioversion (Equipment currently on board, efficacy not demonstrated in space environment) [CRL 1]
Nutritional countermeasure [CRL 2]
Pharmaceutical countermeasure [CRL 1]
Pre-flight and in-flight testing and monitoring to assess altered susceptibility to dysrhythmias [CRL 7]</td></tr>
<tr><td>Research & Technology Questions [With Mission Priority]:</td><td><table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td>5a</td><td>Does space flight increase susceptibility to serious cardiac dysrhythmias? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>5b</td><td>What conditions of space flight (e.g., microgravity, disruption of physiological rhythms, nutrition, environmental factors and radiation) may be responsible for cardiac dysrhythmias, and what are the mechanisms involved? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>5c</td><td>Can risk of serious cardiac dysrhythmias be predicted for individual crewmembers? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>5d</td><td>What countermeasures may prevent or reduce the occurrence of serious cardiac dysrhythmias during long-term space flight? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>5e</td><td>Can susceptibility to, and occurrence of, serious cardiac dysrhythmias be effectively diagnosed and treated during space flight? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>5f</td><td>Which cardiovascular diseases are likely to be aggravated by space flight, and what mechanisms are involved? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>5g</td><td>What screening methods on the ground and in-flight might identify crewmembers with underlying cardiovascular disease, which may be aggravated by space flight? [ISS 1, Lunar 1, Mars 1]</td></tr>
</table></td></tr>
<tr><td>Related Risks :</td><td><table>
<tr><td>Cardiovascular Alterations</td></tr>
<tr><td>Diminished Cardiac and Vascular Function</td></tr>
<tr><td>Environmental Health</td></tr>
<tr><td>Define Acceptable Limits for Contaminants in Air and Water</td></tr>
<tr><td>Skeletal Muscle Alterations</td></tr>
<tr><td>Reduced Muscle Mass, Strength, and Endurance</td></tr>
<tr><td>Increased Susceptibility to Muscle Damage</td></tr>
<tr><td>Nutrition</td></tr>
<tr><td>Inadequate Nutrition</td></tr>
<tr><td>Clinical Capabilities</td></tr>
<tr><td>Monitoring and Prevention</td></tr>
<tr><td>Major Illness and Trauma</td></tr>
<tr><td>Pharmacology of Space Medicine Delivery</td></tr>
<tr><td>Ambulatory Care</td></tr>
<tr><td>Rehabilitation on Mars</td></tr>
<tr><td>Radiation</td></tr>
<tr><td>Acute and Late CNS Risks</td></tr>
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	Chronic and Degenerative Tissue Risks Acute Radiation Risks
Important References :	Fritsch-Yelle JM, Leuenberger UA, D'Aunno DS, Rossum AC, Brown TE, Wood ML, Josephson ME, Goldberger AL. An Episode of Ventricular Tachycardia During Long-Duration Spaceflight. The American Journal of Cardiology. 1998 June;81: 1391-1392. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=9631987 Smith RF, Stanton K, Stoop D, Brown D, Januez W, King P. Vectorcardiographic Changes During Extended Space flight (M093): Observations at Rest and During Exercise. In: Biomedical Results of Skylab (NASA SP-377). Johnston RS and Dietlein LF, editors. Washington, DC: NASA 339-350, 1977. Rossum AC, Wood ML, Bishop Sl, Deblcok H, Charles JB. Evaluation of Cardiac Rhythym Disturbances During Extravehicular Activity. The American Journal of Cardiology. 1997 April;79: 1153-1155. Charles JB, Bungo MW, Fortner GW. Cardiopulmonary Function. In: Nicogossian A, Huntoon C, Pool S, and (editors). Space Physiology and Medicine. 3rd ed. Philadelphia, PA: Lea & Febiger, 286-304, 1994.

Risk Title: Diminished Cardiac and Vascular Function

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Cardiovascular Alterations
Risk Number :	6
Risk Description :	Diminished cardiac function, orthostatic or postural hypotension, and the impaired ability to perform strenuous tasks on a planetary surface may occur due to prolonged exposure to hypogravity.
Context / Risk Factors :	This risk may be influenced by altered neural and hormonal regulation, flight duration, or gender.
Justification / Rationale :	Some, but not all, studies suggest that prolonged exposure to microgravity may lead to reduction of cardiac mass and reduced cardiac function. Carefully controlled inflight studies are required to document this finding and determine the clinical signficance.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 2 **Mars:** Priority 2
Current Countermeasures :	• In flight exercise
Projected Countermeasures or Mitigations & other Deliverables:	• Artificial G exposure • Drugs that affect cardiac mass and function • Improved exercise and conditioning program
Research & Technology Questions [With Mission Priority]:	

No.	Question
6a	Does long-duration space flight lead to diminished cardiac function? If so, what mechanisms are involved? **[ISS 1, Lunar 1, Mars 1]**
6b	Is space flight induced diminished cardiac function reversible? **[ISS 1, Lunar 1, Mars 1]**
6c	What is the extent of reduction in cardiac function and/or mass associated with long-duration space flight? **[ISS 1, Lunar 1, Mars 1]**
6d	Can susceptibility to reduced cardiac function be predicted for individual crewmembers? **[ISS 2, Lunar 2, Mars 2]**

	6e	What countermeasures may be effective in mitigating the occurrence of reduced cardiac function or mass? **[ISS 1, Lunar 1, Mars 1]**
	6f	What are the physiological and environmental factors by which space flight decreases orthostatic tolerance? **[ISS 1, Lunar 1, Mars 1]**
	6g	How does duration of space flight affect the severity and time course of orthostatic intolerance, and what are the mechanisms? **[ISS 2, Lunar 2, Mars 2]**
	6h	Is orthostatic intolerance likely to develop on the surface of Mars or the moon? **[ISS 1, Lunar 1, Mars 1]**
	6i	Can space flight induced orthostatic intolerance be predicted for individual crewmembers? **[ISS 1, Lunar 1, Mars 1]**
	6j	What countermeasures can be developed to overcome or prevent orthostatic intolerance? **[ISS 1, Lunar 1, Mars 1]**
	6k	What are the physiological and environmental factors by which space flight decreases aerobic exercise capacity? **[ISS 1, Lunar 1, Mars 1]**
	6l	Is the observed decrease in exercise capacity directly related to duration of space flight? **[ISS 1, Lunar 1, Mars 1]**
	6m	Can the degree of reduced aerobic exercise capacity be predicted for individual crewmembers? **[ISS 1, Lunar 1, Mars 1]**
	6n	What countermeasures can be developed to overcome microgravity-induced reduction in aerobic exercise capacity? **[ISS 1, Lunar 1, Mars 1]**

Related Risks :	**Bone Loss**
	Accelerated Bone Loss and Fracture Risk
	Injury to Joints and Intervertebral Structures
	Cardiovascular Alterations
	Occurrence of Serious Cardiac Dysrhythmias
	Environmental Health
	Define Acceptable Limits for Contaminants in Air and Water
	Skeletal Muscle Alterations
	Reduced Muscle Mass, Strength, and Endurance
	Increased Susceptibility to Muscle Damage
	Clinical Capabilities
	Monitoring and Prevention
	Major Illness and Trauma
	Pharmacology of Space Medicine Delivery
	Ambulatory Care
	Rehabilitation on Mars
Important References :	Blomqvist LD, Lane CG, Wright SJ, Meny GM, Levine BD, Buckey JC, Peshock RM, Weatherall P, Stray-Gundersen J, Gaffney FA, Watenpaugh DE, Arbeille P, and Baisch F. Cardiovascular regulation in microgravity. In: Scientific Results of the German Spacelab Mission D-2: Proceedings of the Norderney Symposium, edited by Sahm PR, Keller MH, and Schiewe B.. Koln, Germany: Wissenschaftliche Projektfuhrung D-2 (c/o Deutsches Zentrum fur Luft- und Raumfahrt), 1994, p. 688-690.
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Risk Title: Define Acceptable Limits for Contaminants in Air and Water

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Environmental Health
Risk Number :	7
Risk Description :	Crew health and performance may be jeopardized due to the inability to define acceptable limits for contaminants.
Context / Risk Factors :	This risk may be influenced by remoteness, crew health, or crew susceptibility to degree of system closure.
Justification / Rationale :	Excessive pollutant levels (including microbial contaminants) can jeopardize crew health and/or impair mission success. The severity and likelihood of any adverse effects depends on the specific pollutant and its measured concentration.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Identification of possible contaminants • Restriction on types of materials allowed in flight • Preflight off-gassing of certain materials
Projected Countermeasures or Mitigations & other Deliverables:	• Identification of possible contaminants
Research & Technology Questions [With Mission Priority]:	

No.	Question
7a	What are the most likely sources of severe air and water pollution specific to ISS, lunar, and Mars missions, and what methods can be used to control these sources over long periods of time? **[ISS 1, Lunar 1, Mars 1]**
7b	What are the tolerance limits in terms of quantity and type of microorganisms in air, water, and food, and on surfaces? **[ISS 1, Lunar 1, Mars 1]**
7c	What approaches to setting exposure standards may be used when insufficient data are available to allow prediction of acceptable exposure levels? **[ISS 1, Lunar 1, Mars 1]**
7d	What is the requirement for determining how rapidly acceptable air quality can be recovered after a severe pollution condition and what effect that recovery has on humidity condensate and the water recovery system? **[ISS 1, Lunar 1, Mars 1]**
7e	Can automated real-time systems be used to monitor air and water quality for lunar and Mars missions, and can the crew interpret results without ground support? **[ISS 1, Lunar 1, Mars 1]**
7f	How can traditional limited-time exposure and human toxicological data be used to predict acceptable values for inhalation exposures to single chemicals and/or mixtures? **[ISS 2, Lunar 2, Mars 2]**
7g	What impact do space flight induced, biological, physiological, and immunological changes have on the susceptibility of crewmembers to infectious agents and toxic substances in the air and water? **[ISS 2, Lunar 2, Mars 2]**
7h	What are the effects of exposure to ultra fine and larger (respirable and non-respirable) particles (e.g., lunar dust) on crew health, safety and performance? **[ISS 3, Lunar 2, Mars 2]**
7i	What are the interactions of microbes, chemicals and plants in CELSS on air quality? **[ISS 3, Lunar 2, Mars 2]**
7j	To the extent that plants are critical to mission success, will the potential for phytotoxicity be adequately addressed in the evaluation of air quality? **[ISS 3, Lunar 3, Mars 2]**

	7k	Is there potential for increased heterogeneity in terms of the distribution of air contaminants in the relatively larger lunar and Mars habitats? If so, what additional monitoring resources and/or strategies are necessary to protect crew health? **[ISS 3, Lunar 2, Mars 2]**
Related Risks :		**Immunology & Infection**
		Immune Dysfunction, Allergies and Autoimmunity
		Interaction of Space flight Factors, Infections and Malignancy
		Alterations in Microbes and Host Interactions
		Advanced Environmental Monitoring & Control
		Monitor Air Quality
		Monitor External Environment
		Monitor Water Quality
		Monitor Surfaces, Food, and Soil
		Provide Integrated Autonomous Control of Life Support Systems
		Advanced Extravehicular Activity
		Provide Space Suits and Portable Life Support Systems
		Advanced Food Technology
		Maintain Food Quantity and Quality
		Advanced Life Support
		Maintain Acceptable Atmosphere
		Maintain Thermal Balance in Habitable Areas
		Provide and Maintain Bioregenerative Life Support Systems
Important References :		Huntoon CL. Toxicological Analysis of STS-40 Atmosphere, NASA/JSC Memorandum, SD4/01 -93-251, July 6, 1991; Toxicological Analysis of STS-55 Atmosphere, NASA/JSC Memorandum SD4-93-251, July 6, 1993.
		James JT. Toxicological Assessment of Air Contaminants during the Mir 19 Expedition, 1996
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		Nicogossian AE, et al. Crew Health in the Apollo-Soyuz Test Project Medical Report, NASA SP-411, 1977
		Pool SL. Ethylene Glycol Treatise. NASA/JSC Memorandum SD2-97-542, September 15, 1997.

Risk Title: Immune Dysfunction, Allergies and Autoimmunity

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Immunology & Infection
Risk Number :	8
Risk Description :	Atopic and autoimmune diseases may occur due to long-term space flight effects on immune-regulatory pathways or on specific immune cells.
Context / Risk Factors :	This risk may be influenced by radiation, microgravity, isolation, stress (e.g., sleep deprivation, extreme environments, and nutritional deprivation), or crewmember genetics.
Justification / Rationale :	In vitro studies have demonstrated that contributing risk factors of space flight collectively have a powerful effect upon the cells of the immune system: T cells, particularly CD4+ (helper) T cells, B cells, NK cells, monocyte/ macrophages/dendritic cells, hematopoietic stem cells and cytokine networks can be negatively affected. Alterations in one or more immune system regulatory network (i.e. cells or cell products) could affect homeostasis, which could result in allergic (atopic) or autoimmune disease. The relatively short time of the lunar mission (10-44 days) would tend to

	reduce the risk of developing immunodeficiency or atopic disease. The long-term exposure (>1 year) to deep-space radiation, to microgravity (> 2 years), and to other conditions of space flight during a Mars mission would offer the greatest challenge to the host immune system.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 2 **Mars:** Priority 2
Current Countermeasures :	• Assessment of crewmembers for prior autoimmune or atopic disorders. • Radiation shielding • Monitor and limit exposure to radiation and other environmental factors
Projected Countermeasures or Mitigations & other Deliverables:	• Definition of surrogate markers of immune function that will allow for the monitoring of immune cells and/or immune system compartments during a long-duration space flight • Definition of the background of crewmembers to identify individuals more likely to develop autoimmune or atopic disease • Detection systems for assessment of immune function [CRL 2]
Research & Technology Questions [With Mission Priority]:	(see table below)

No.	Question
8a	What are the molecular and genetic mechanisms that are affected by space flight related environments (e.g., radiation, microgravity, stress, isolation, sleep deprivation, extreme environments, nutritional deficiency, and social interactions) that can result in the loss of immunoregulation/immune tolerance and/or affect innate/acquired immunity, respectively? **[ISS 1, Lunar 1, Mars 1]**
8b	Can the effects on immune function (innate/acquired immunity), or dysfunction (loss of tolerance/immune surveillance) be summarized as a consequence of the conditions relating to each mission and/or its duration (i.e., 1-year ISS, 30-day lunar, 30-month Mars)? **[ISS 1, Lunar 1, Mars 1]**
8c	What autoimmune diseases or allergies may affect astronauts exposed to space flight environments of different missions and/or durations? **[ISS 1, Lunar 1, Mars 1]**
8d	Are there detection systems that can identify the first alterations in immune regulatory networks (identify surrogate markers of immune function/dysfunction) so that therapeutic interventions can be instituted? **[ISS 2, Lunar 2, Mars 2]**
8e	What steps can be taken during space flight to modify immune function as it relates to autoimmunity or atopic disease? **[ISS 2, Lunar 2, Mars 2]**
8f	Will it be possible to use immuno-regulatory agents to prevent immune imbalances with respect to the development of atopic or autoimmune diseases? **[ISS 1, Lunar 1, Mars 1]**
8g	Will nutritional supplements be able to modify immune responses by working in concert with other immuno-modulators to reduce atopic and/or autoimmune disease? **[ISS 1, Lunar 1, Mars 1]**
8h	What pharmalogical agents used during long-term space flights, or interactions between pharmalogical agents, negatively affect the immune system? **[ISS 1, Lunar 1, Mars 1]**

Related Risks :

Environmental Health
Define Acceptable Limits for Contaminants in Air and Water
Immunology & Infection
Interaction of Space flight Factors, Infections and Malignancy
Alterations in Microbes and Host Interactions
Nutrition
Inadequate Nutrition
Clinical Capabilities

	Monitoring and Prevention
	Major Illness and Trauma
	Pharmacology of Space Medicine Delivery
	Ambulatory Care
	Rehabilitation on Mars
	Behavioral Health & Performance and Space Human Factors (Cognitive)
	Human Performance Failure Due to Poor Psychosocial Adaptation
	Human Performance Failure Due to Neurobehavioral Problems
	Mismatch between Crew Cognitive Capabilities and Task Demands
	Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems
	Radiation
	Carcinogenesis
	Acute and Late CNS Risks
	Chronic and Degenerative Tissue Risks
	Acute Radiation Risks
	Advanced Food Technology
	Maintain Food Quantity and Quality
Important References :	Aviles H, Belay T, Vance M, Sonnenfeld G. Increased levels of catecholamines correlate with decreased function of the immune system in the hindlimb-unloading rodent model of spaceflight (Abstract 107). Gravit Space Biol Bull. 17:56, 2003.
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Risk Title: Interaction of Space flight Factors, Infections and Malignancy

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Immunology & Infection
Risk Number :	9
Risk Description :	Increased risk of infections or cancers may result from immune dysfunction caused by the interaction of space flight factors.
Context / Risk Factors :	In addition to space flight related immune dysfunction, which can increase the risk of infections in crewmembers, microgravity can also affect microorganisms in a variety of ways. Furthermore, several neoplastic malignancies have been associated with a variety of human pathogens. This risk may be influenced by immune dysfunction, latent viral infections, commensal organisms, or host genetics.
Justification / Rationale :	Every component of immune resistance to infection is compromised under space flight conditions. As a result, bacterial, fungal, or viral infections may be more likely in space flight environments (though this has not been documented). In particular, latent viruses (e.g., Epstein-Barr virus, herpes simplex, polyomaviruses, and Hepatitis viruses) can become active and potentially initiate tumor formation. The length and severity of space flight conditions on the Martian mission are expected to pose the highest (though still low probability) risk for the development of immune cell-mediated leukemias and lymphomas.

Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 3 **Mars:** Priority 2
Current Countermeasures :	• Pre-flight quarantine (Health Stabilization Program) • Radiation shielding. • Monitoring exposure to radiation and other environmental factors • Ongoing crew health monitoring • Onboard antibiotics, anti-viral and anti-fungal agents, immunizations, sterilization procedures, use of clean vehicles • Air and water monitoring • Regular inflight 'housecleaning'
Projected Countermeasures or Mitigations & other Deliverables:	• Anti-microbial agents [CRL 4] • Fusion proteins to block virus re-infection [CRL 6] • Molecular detection systems for surface, water and airborne pathogens (See AHST Risks 34, 36, & 37) [CRL 7] • Molecular diagnostic/detection kits and equipment to classify infectious agents [CRL 6] • Pathogen-specific immunizations [CRL 2] • Pre-flight crew screening for the presence of microorganisms [CRL 2]

Research & Technology Questions [With Mission Priority]:

No.	Question
9a	What types of latent infections (e.g., viral infections) will become reactivated as a function of space flight associated factors and pose the greatest threat to human health as a function of compromised immunity resulting from space travel? **[ISS 1, Lunar 1, Mars 1]**
9b	What commensal organisms have the potential of establishing a primary infection and pose the greatest threat to human health as a function of compromised immunity resulting from space travel? **[ISS 1, Lunar 1, Mars 1]**
9c	What diagnostic, environmental monitoring, or laboratory technologies need to be developed for the identification of pathogenic microorganisms, and prevention or diagnosis of infectious diseases while in space (e.g., bacterial, viral, or fungal typing in real-time)? **[ISS 1, Lunar 1, Mars 1]**
9d	Will the severity of disease(s) resulting from latent infection reactivation, and/or infections caused by commensal organisms (as a function of space flight associated factors), be affected by the space mission and/or its duration (i.e., 1-year ISS, 30-day lunar, 30-month Mars)? **[ISS 1, Lunar 1, Mars 1]**
9e	Are there neoplastic malignancies that may result from latent infection reactivation, and/or infections caused by commensal organisms (as a function of space flight associated factors), that will be affected by the space mission and/or its duration? **[ISS 2, Lunar 2, Mars 2]**
9f	Is it possible to predict the summary effects of each component condition and duration of space flight that results in an infectious and/or neoplastic state? **[ISS 2, Lunar 2, Mars 2]**
9g	Will it be possible to develop nutritional supplements to augment anti-microbial and/or anti-tumor therapies? **[ISS 2, Lunar 2, Mars 2]**
9h	Will it be possible to restore immunity in a severely immunocompromised astronaut with autologous stem cell transplants? **[ISS 3, Lunar 3, Mars 3]**

	9i	What steps can be taken during space flight to boost immune function, and what antimicrobial therapies and immunological treatments can be used to prevent or cure infections? **[ISS 2, Lunar 2, Mars 2]**
	9j	Will it be possible to use anti-viral, -bacterial, or -fungal agents aboard spaceships to reduce pathogen burdens or to treat infections? **[ISS 2, Lunar 2, Mars 2]**
	9k	Will therapeutic agents aboard spacecraft function to reduce or treat tumor development? **[ISS 3, Lunar 3, Mars 3]**

Related Risks :	**Environmental Health**
	Define Acceptable Limits for Contaminants in Air and Water
	Immunology & Infection
	Immune Dysfunction, Allergies and Autoimmunity
	Alterations in Microbes and Host Interactions
	Nutrition
	Inadequate Nutrition
	Clinical Capabilities
	Monitoring and Prevention
	Major Illness and Trauma
	Pharmacology of Space Medicine Delivery
	Ambulatory Care
	Rehabilitation on Mars
	Behavioral Health & Performance and Space Human Factors (Cognitive)
	Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems
	Radiation
	Carcinogenesis
	Acute and Late CNS Risks
	Chronic and Degenerative Tissue Risks
	Acute Radiation Risks
	Advanced Environmental Monitoring & Control
	Monitor Surfaces, Food, and Soil
	Advanced Food Technology
	Maintain Food Quantity and Quality

Important References :	Aviles H, Belay T, Fountain K, Vance M, Sonnenfeld G. Increased susceptibility to Pseudomonas aeruginosa infection hindlimb unloading conditions. J Appl Physiol. 95:73-80, 2003. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12626488
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Risk Title: Alterations in Microbes and Host Interactions

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Immunology & Infection
Risk Number :	10
Risk Description :	Alterations in microbes and host interactions due to exposure to space flight conditions may result in previously innocuous microorganisms endangering the crew and life support systems.
Context / Risk Factors :	This risk may be influenced by extreme environments, isolation, microbial contamination, microgravity, nutritional deprivation, radiation, sleep deprivation, or stress.
Justification / Rationale :	Long-duration space flight may result in alterations in the host/microbe relationship that may lead to a difficult to control, or severe, infection. In particular, the long-duration and severe nature of space flight conditions on a Mars mission might increase the risk. The short-duration of the Lunar mission is not likely to provide sufficient time for significant alterations in the host/microbe relationship.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 3 **Mars:** Priority 2
Current Countermeasures :	• In-flight environmental monitoring and bioburden reduction procedures (cleaning, filtering etc.)
Projected Countermeasures or Mitigations & other Deliverables:	• Comprehensive microbial identification technology [CRL 5] • Pre-flight screening [CRL 7] • Routine in-flight microbial identification/monitoring capability [CRL 6]
Research & Technology Questions [With Mission Priority]:	

No.	Question
10a	What technologies will monitor, detect, quantify or identify microorganisms that pose a threat to human health during a mission as a countermeasure for preventing further contamination or disease (e.g., bacterial, viral, or fungal typing in real-time)? **[ISS 1, Lunar 1, Mars 1]**
10b	Does the spacecraft environment exert selective pressure on microorganisms that presents the crew with increased health risks (e.g., Helicobacter and ulcers)? **[ISS 1, Lunar 1, Mars 1]**
10c	Does space flight alter microbial growth rates, mutation rates, or pathogenicity? **[ISS 1, Lunar 1, Mars 1]**
10d	Does space flight alter the exchange of genetic material between microorganisms? **[ISS 1, Lunar 1, Mars 1]**
10e	Does space flight alter host:microbe balance? **[ISS 1, Lunar 1, Mars 1]**
10f	Do microorganisms associated with biological life support systems or biological waste treatment systems enter the general spacecraft environment with consequent increase in health risks? **[ISS 3, Lunar 1, Mars 1]**

Related Risks :	**Environmental Health** Define Acceptable Limits for Contaminants in Air and Water **Immunology & Infection** Immune Dysfunction, Allergies and Autoimmunity Interaction of Space flight Factors, Infections and Malignancy **Clinical Capabilities** Monitoring and Prevention **Radiation** Acute Radiation Risks **Advanced Environmental Monitoring & Control** Monitor Surfaces, Food, and Soil **Advanced Life Support** Manage Waste
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Risk Title: Reduced Muscle Mass, Strength, and Endurance

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Skeletal Muscle Alterations
Risk Number :	11
Risk Description :	Performance of mission related physical activities may be impaired due to loss of muscle mass, strength, and endurance associated with prolonged exposure to hypogravity.
Context / Risk Factors :	Decreased loading of skeletal muscle during space flight is associated with decreased muscle size, reduced muscle endurance, and loss of muscle strength. The risk may be influence by sensory-motor deficits, contractile protein loss, changes in contractile phenotype, reduced oxidative capacity, bone loss, poor nutrition, or insufficient exercise.
Justification / Rationale :	There is a growing database demonstrating that skeletal muscles, particularly postural muscles of the lower limb, undergo atrophy and undergo structural and metabolic alterations during space flight. These alterations, if unabated, may affect performance of mission tasks. Exercise countermeasures have to-date not fully protected muscle integrity. ISS experience will guide countermeasure strategies for Mars missions.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 3 **Mars:** Priority 2
Current Countermeasures :	• Cycle ergometer • Moderate resistance exercise • Treadmill
Projected Countermeasures or Mitigations & other Deliverables:	• Artificial gravity (e.g., centrifuge with exercise capabilities) [TRL 3] • New programs of heavy resistance exercise (e.g., expanded exercise and loading capabilities) and/or biophysical interventions [TRL 6] • Pharmacological interventions [TRL 2]

	• Biophysical interventions [TRL 4] • New/improved programs of endurance exercise [TRL 6] • Nutritional interventions [TRL 6]
Research & Technology Questions [With Mission Priority]:	(see table below)

No.	Question
	Global/Systemic
11a	Can any one or combination of non-invasive modalities (exercise regimens, artificial gravity, etc.) protect or build skeletal muscle mass or maintain skeletal muscle strength or preserve skeletal muscle endurance during an ISS, lunar, or Mars mission? **[ISS 1, Lunar 1, Mars 1]**
11b	Can non-invasive countermeasures (resistive exercise, artificial gravity, etc.) aimed at counteracting atrophy processes during an ISS, lunar, or Mars mission maintain those deficits in skeletal muscle strength that appear to occur independently of the atrophy process? **[ISS 1, Lunar 1, Mars 1]**
11c	What combination of non-invasive modalities (exercise regimens, etc.), nutritional and micronutrient supplements, and hormonal or pharmacological interventions is most effective and efficient in protecting or increasing skeletal muscle mass, strength, and endurance prior to or during space flight? **[ISS 1, Lunar 1, Mars 1]**
11d	What hardware and/or technology is/are reliable and effective in preserving skeletal muscle mass, strength, and endurance during an ISS, lunar, or Mars mission? **[ISS 3, Lunar 3, Mars 3]**
11e	What technologies (e.g., ultrasound) can be used to monitor and quantify changes in skeletal muscle size, strength, and endurance during space flight? **[ISS 3, Lunar 3, Mars 3]**
11f	Does atrophy of the spinal musculature contribute to lower back pain in crewmembers during space flight or upon returning from an ISS, lunar, or Mars mission? **[ISS 3, Lunar 3, Mars 3]**
11g	What are the effects of skeletal muscle atrophy on whole body metabolism (e.g., insulin and glucose tolerance) during space flight? **[ISS 1, Lunar 3, Mars 1]**
11h	What are the effects of skeletal muscle atrophy on thermoregulation during space flight? **[ISS 3, Lunar 3, Mars 3]**
11i	What assistance devices/technologies can compensate for losses in skeletal muscle strength and endurance during space flight? **[ISS 3, Lunar 3, Mars 3]**
11j	Is the skeletal muscle atrophy, loss in skeletal muscle strength, and reduction in skeletal muscle endurance that occurs during an ISS, lunar, or Mars mission completely reversible upon return to Earth? **[ISS 3, Lunar 3, Mars 3]**
11k	What prescription modality(ies) (exercise regimens, physical therapy, etc.) facilitate recovery of skeletal muscle mass, strength, and endurance in crewmembers returning from an ISS, lunar, or Mars mission? **[ISS 1, Lunar 1, Mars 1]**
	Nutrition
11l	What are the nutritional and micronutrient requirements to maintain skeletal muscle mass during ISS, lunar, or Mars missions? (See also 16g and 16h) **[ISS 3, Lunar 3, Mars 3]**
	Skeletal Muscle/Cellular
11m	What cellular processes/signaling pathways (e.g. protein turnover) in skeletal muscle can be identified and targeted (pharmacological, gene therapy, hormones, etc.) to prevent or attenuate fiber atrophy, loss of skeletal muscle strength, and reductions in skeletal muscle endurance during ISS, lunar, or Mars missions? **[ISS 3, Lunar 3, Mars 3]**
11n	Is the capacity of skeletal muscle to grow or regenerate (satellite cells) compromised during or after a mission because of space flight conditions (e.g., radiation exposure, reduced skeletal muscle tension)? **[ISS 3, Lunar 2, Mars 1]**
	Cardiovascular

	11o	Does skeletal muscle atrophy of the lower extremity musculature (i.e. muscle pump) affect cardiovascular function (e.g., orthostatic hypotension) during an ISS, lunar, or Mars mission? **[ISS 1, Lunar 1, Mars 1]**
		Bone/Tendon
	11p	Does site-specific skeletal muscle atrophy contribute to the accelerated rate of bone loss in the central and peripheral skeleton because of countermeasures targeting select muscle groups and/or reduced forces at the tendon insertion sites during space flight? **[ISS 1, Lunar 2, Mars 1]**
	11q	What are the temporal relationships between the changes in structure and function of the bone, tendon, skeletal muscle, skeletal muscle-tendon interface, and skeletal muscle -bone interactions during space flight? **[ISS 2, Lunar 2, Mars 2]**
	11r	How does the atrophy process affect the structural and functional properties of connective tissue (tendons), the fiber-tendon interface and the tendon-bone interface during space flight? **[ISS 2, Lunar 2, Mars 2]**
		Sensory-Motor
	11s	How do the deficits in skeletal muscle mass associated with space flight affect the structural/functional properties of the sensory system and motor nerves? **[ISS 1, Lunar 1, Mars 1]**
	11t	To what extent do alterations in the sensory-motor system contribute to deficits in skeletal muscle strength and endurance during space flight? **[ISS 3, Lunar 3, Mars 3]**
Related Risks :		**Bone Loss**
		Accelerated Bone Loss and Fracture Risk
		Impaired Fracture Healing
		Injury to Joints and Intervertebral Structures
		Cardiovascular Alterations
		Occurrence of Serious Cardiac Dysrhythmias
		Diminished Cardiac and Vascular Function
		Skeletal Muscle Alterations
		Increased Susceptibility to Muscle Damage
		Sensory-Motor Adaptation
		Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing
		Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation
		Nutrition
		Inadequate Nutrition
		Clinical Capabilities
		Monitoring and Prevention
		Pharmacology of Space Medicine Delivery
		Ambulatory Care
		Rehabilitation on Mars
		Radiation
		Chronic and Degenerative Tissue Risks
		Advanced Food Technology
		Maintain Food Quantity and Quality

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Risk Title: Increased Susceptibility to Muscle Damage

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Skeletal Muscle Alterations

Risk Number :	12
Risk Description :	Risk of injury to skeletal muscle and associated connective tissues may be increased due to remodeling and weakening associated with prolonged exposure to hypogravity.
Context / Risk Factors :	Decreased loading of the musculoskeletal system during space flight is associated with skeletal muscle atrophy, changes in structural proteins, and remodeling of associated connective tissues (i.e., intramuscular, skeletal muscle tendon interface, etc.). This risk may be influenced by neural factors, oxidative capacity, nutrition, or exercise.
Justification / Rationale :	Skeletal muscle and associated connective tissue remodeling and weakening that result from hypogravity exposure lead to a greater likelihood of sustaining skeletal muscle and/or connective tissue damage and soreness ,which could result in an inability or reduced ability to perform mission-directed activities. The risk will increase with mission duration.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 3 **Mars:** Priority 2
Current Countermeasures :	• Cycle ergometer • Moderate resistance exercise • Treadmill • Conditioning
Projected Countermeasures or Mitigations & other Deliverables:	• Artificial gravity (e.g., centrifuge with exercise capabilities) [TRL 3] • New programs of heavy resistance exercise (e.g., expanded exercise and loading capabilities) and/or biophysical interventions [TRL 6] • Pharmacological interventions [TRL 2]
Research & Technology Questions [With Mission Priority]:	(see table below)

No.	Question
12a	What prescription guidelines and compliance factors facilitate increased resistance to skeletal muscle and associated connective tissue injury in crewmembers prior to space flight? **[ISS 3, Lunar 3, Mars 3]**
12b	What hardware and/or technology is/are effective in preserving muscle structure during an ISS mission? **[ISS 3, Lunar N/A, Mars N/A]**
12c	What hardware and/or technology is/are effective in preserving muscle structure during a lunar mission? **[ISS N/A, Lunar 3, Mars N/A]**
12d	What hardware and/or technology is/are effective in preserving muscle structure during a Mars mission? **[ISS N/A, Lunar N/A, Mars 3]**
12e	Do countermeasure paradigms that counteract skeletal muscle atrophy processes during an ISS mission improve the structure-function properties of connective tissue systems? **[ISS 2, Lunar N/A, Mars N/A]**
12f	Do countermeasure paradigms that counteract skeletal muscle atrophy processes during a lunar mission improve the structure-function properties of connective tissue systems? **[ISS N/A, Lunar 2, Mars N/A]**
12g	Do countermeasure paradigms that counteract skeletal muscle atrophy processes during a Mars mission improve the structure-function properties of connective tissue systems? **[ISS N/A, Lunar N/A, Mars 2]**
12h	Do countermeasures that minimize atrophy processes and strengthen skeletal muscle tendon properties that are performed in states of unloading prevent injury from occurring during a mission and upon return to weight bearing states (e.g., 1-G)? **[ISS 1, Lunar 1, Mars 1]**
12i	What are the prescription guidelines and compliance factors needed for countermeasures (exercise, AG, etc.) during space flight to minimize susceptibility to skeletal muscle damage? **[ISS 1, Lunar 1, Mars 1]**

	12j	If a skeletal muscle injury occurs during space flight, what hardware and/or technology (e.g., strength measurement, muscle/connective tissue damage marker(s), pain surveys, diagnostic ultrasound) can be used to determine when it is safe for a crewmember to resume exercise or perform dynamic activities associated with the mission (e.g., EVA/exploration)? **[ISS 1, Lunar 1, Mars 1]**
	12k	What are the assistance devices/technologies that can compensate for a skeletal muscle and/or associated connective tissue injury during space flight? **[ISS 3, Lunar 3, Mars 3]**
	12l	What prescription guidelines and compliance factors facilitate injury-free skeletal muscle rehabilitation in crewmembers returning from an ISS mission? **[ISS 1, Lunar N/A, Mars N/A]**
	12m	What prescription guidelines and compliance factors facilitate injury-free skeletal muscle rehabilitation in crewmembers returning from a lunar mission? **[ISS N/A, Lunar 1, Mars N/A]**
	12n	What prescription guidelines and compliance factors facilitate injury-free skeletal muscle rehabilitation in crewmembers returning from a Mars mission? **[ISS N/A, Lunar N/A, Mars 1]**

Related Risks :	**Bone Loss**
	Accelerated Bone Loss and Fracture Risk
	Impaired Fracture Healing
	Injury to Joints and Intervertebral Structures
	Cardiovascular Alterations
	Occurrence of Serious Cardiac Dysrhythmias
	Diminished Cardiac and Vascular Function
	Skeletal Muscle Alterations
	Reduced Muscle Mass, Strength, and Endurance
	Clinical Capabilities
	Monitoring and Prevention
	Ambulatory Care
	Rehabilitation on Mars
	Radiation
	Chronic and Degenerative Tissue Risks
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Risk Title: Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Sensory-Motor Adaptation
Risk Number :	13
Risk Description :	Operational performance may be impaired by spatial disorientation, perceptual illusions, and/or disequilibrium which may occur during and after g-transitions due to maladaptation of the sensory-motor systems to the new gravito-inertial environment.
Context / Risk Factors :	This risk may be exacerbated by vehicle/habitat designs that do not maintain consistent architectural frames of reference or those presenting ambiguous visual orientation cues. It may also be exacerbated by low visibility situations (smoke, landing weather, poor lighting), environmental vibration, or unstable support surfaces (floors, seats).

Justification / Rationale :	Transitions between gravitational and dynamic acceleration environments are associated with sensory-motor adaptation mechanisms and potential adverse sensory conflict reactions. These may be problematic during periods requiring crew control of vehicles or other complex systems. These mechanisms and reactions are expressed with a high degree of individual variability due to crew training, crew experience, and other factors not well understood. Crew performance of routine and critical actions during launch, landing, and the periods immediately following these events may be compromised.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 2 **Mars:** Priority 2
Current Countermeasures :	<u>**Landing**</u> • Heads Up Display • Education and Training <u>**In-Flight**</u> • Vehicle architecture and layout to establish a sense of artificial vertical for individual modules (luminous exit placards to mark emergency egress paths, rack orientation and module layout, surface labels) • Preflight education and training in module simulators • EVA training in neutral buoyancy • Virtual reality techniques
Projected Countermeasures or Mitigations & other Deliverables:	• Auto-land capability on lunar or Mars landing and return vehicles [Lunar] [Mars] • Determine efficacy of re-adaptation head movements during entry [CRL 2] • Improved standards for workstation and spacecraft interior architecture [CRL 4] • Improved teleoperator displays [CRL 2] • Pre-flight or in-flight g- specific pre-adaptation techniques, (e.g., artificial gravity) [CRL 2] [Lunar] [Mars] • Pre-flight visual orientation training for IVA activities using VR techniques[CRL 2-5] • Preflight training, including high fidelity simulators [CRL 2] [Lunar] [Mars] • Spatial ability tests should be developed and validated to predict and improve individual performance [CRL 2] • Evaluate in-flight landing rehearsal simulators [CRL 2]
Research & Technology Questions [With Mission Priority]:	

No.	Question
13a	What are the physiological bases for spatial disorientation, perceptual illusions, and vertigo? **[ISS 1, Lunar 1, Mars 1]**
13b	What combinations of visual, vestibular, and haptic cues cause spatial disorientation, perceptual illusions, and vertigo during and after g-transitions? **[ISS 2, Lunar 2, Mars 2]**
13c	Can g-transition-related spatial disorientation, perceptual illusions, and vertigo be predicted from mathematical models? **[ISS 3, Lunar 3, Mars 3]**
13d	What individual physiological and behavioral characteristics contribute to the large inter-individual differences in neurovestibular symptoms and signs? **[ISS 1, Lunar 1, Mars 1]**
13e	What individual physiological and behavioral characteristics will best predict susceptibility and adaptability? **[ISS 3, Lunar 3, Mars 3]**

	13f	What is the physiological basis for context-specific-adaptation? **[ISS 1, Lunar 1, Mars 1]**
	13g	To what extent can neurovestibular adaptation to weightlessness and/or artificial gravity take place in context-specific fashion, so crewmembers can be adapted to multiple environments and switch between them without suffering disorientation or motion sickness? **[ISS 2, Lunar 2, Mars 2]**
	13h	What preflight training techniques (e.g., virtual reality simulations, parabolic flight) can be used to alleviate the risks of spatial disorientation, perceptual illusions, and vertigo as astronauts launch, enter, and adapt to 0-G? **[ISS 2, Lunar 2, Mars 2]**
	13i	What in-flight training techniques (e.g., virtual reality simulations, treadmill with vibration isolation system, artificial gravity) can be used to alleviate the risks of vertigo, disorientation, and perceptual illusions as astronauts land and (re)adapt to Earth, Moon, or Mars gravity? **[ISS 3, Lunar 3, Mars 3]**
	13j	Is adaptation to the lunar gravity environment sufficient to reduce incidence of landing vertigo upon return to Earth? **[ISS N/A, Lunar 3, Mars N/A]**
	13k	What artificial gravity exposure regimens (g-level, angular velocity, duration, and repetition) will ameliorate the physiological and vestibular deconditioning associated with hypogravity during transit phases of a mission in order to increase the capability to perform operational tasks during flight, entry and landing? **[ISS N/A, Lunar 5, Mars 5]**
	13l	What level of supervisory control will mitigate the landing vertigo risk in landing on the Moon, Mars, and Earth? **[ISS 4, Lunar 4, Mars 4]**

Related Risks :	**Bone Loss**
	Accelerated Bone Loss and Fracture Risk
	Impaired Fracture Healing
	Injury to Joints and Intervertebral Structures
	Renal Stone Formation
	Cardiovascular Alterations
	Occurrence of Serious Cardiac Dysrhythmias
	Diminished Cardiac and Vascular Function
	Skeletal Muscle Alterations
	Reduced Muscle Mass, Strength, and Endurance
	Increased Susceptibility to Muscle Damage
	Sensory-Motor Adaptation
	Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation
	Motion Sickness
	Clinical Capabilities
	Monitoring and Prevention
	Ambulatory Care
	Rehabilitation on Mars
	Behavioral Health & Performance and Space Human Factors (Cognitive)
	Human Performance Failure Due to Neurobehavioral Problems
	Mismatch between Crew Cognitive Capabilities and Task Demands
	Radiation
	Acute and Late CNS Risks
	Space Human Factors Engineering

	Mismatch Between Crew Physical Capabilities and Task Demands
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Risk Title: Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Sensory-Motor Adaptation
Risk Number :	14
Risk Description :	Capability to egress the vehicle in an emergency or to perform post landing tasks may be compromised by impaired movement and coordination caused by long-term exposure to microgravity.
Context / Risk Factors :	This risk may be exacerbated by duration of microgravity exposure, cardiovascular deconditioning, muscle atrophy, orthostatic intolerance, relative hypovolemia, diminished aerobic capacity, and/or poor task, equipment or vehicle/habitat design.
Justification / Rationale :	Following prolonged microgravity exposure, several deconditioned physiological systems must readapt. Crewmembers may be unable to accomplish certain postflight physical activities involving upright posture, locomotion, and handling loads. Current methods of postflight rehabilitation may not be optimal to restore sensory-motor function.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 2 **Mars:** Priority 2
Current Countermeasures :	• Quantitative post-flight tests of spontaneous, positional and positioning nystagmus, postural stability, dynamic visual acuity, and gait [TRL/CRL 8] • Traditional clinical rehabilitation techniques

Projected Countermeasures or Mitigations & other Deliverables:	• Balance prostheses (e.g., tactile vest) [TRL/CRL6] • g-specific pre-adaptation for Mars landing (e.g., short radius intermittent or large radius continuous artificial gravity) and return to Earth [CRL 2] [Mars] • General or g-specific pre-adaptation techniques, (e.g., in-flight or pre-flight artificial gravity; sensory-motor generalization training techniques [CRL 2] • Improved EVA suits designed to mechanically mitigate fracture risk in the event of falls [TRL 2] [Mars] • Pre-flight or in-flight g- specific pre-adaptation techniques, (e.g., artificial gravity) [CRL2, TRL1] [Lunar] • Quantitative post-flight tests of gaze stability, and locomotion and corner turning stability [TRL 6, CRL 6]

Research & Technology Questions [With Mission Priority]:

No.	Question
14a	What are the physiological bases for disruption of balance, locomotion, and eye-head coordination following g-transitions? **[ISS 1, Lunar 1, Mars 1]**
14b	Can disruption of balance, locomotion, and eye-head coordination following g-transitions be predicted from mathematical models? **[ISS 3, Lunar 3, Mars 3]**
14c	What individual physiological and behavioral characteristics contribute to the large inter-individual differences in neurovestibular symptoms and signs? **[ISS 1, Lunar 1, Mars 1]**
14d	What individual physiological and behavioral characteristics will best predict susceptibility and adaptability? **[ISS 3, Lunar 3, Mars 3]**
14e	What is the physiological basis for context-specific-adaptation? **[ISS 1, Lunar 1, Mars 1]**
14f	How can voluntary head movements during entry and landing be used to accelerate re-adaptation? **[ISS 3, Lunar 3, Mars 3]**
14g	What in-flight training techniques (e.g., virtual reality simulations, treadmill with vibration isolation system, artificial gravity) can be used to alleviate the risks of impaired balance control and movement coordination as astronauts land and (re)adapt to Earth, Moon, or Mars gravity? **[ISS 3, Lunar 3, Mars 3]**
14h	Is adaptation to the lunar gravity environment sufficient to reduce incidence of sensory-motor balance and coordination problems upon return to Earth? **[ISS N/A, Lunar TBD, Mars N/A]**
14i	What artificial gravity exposure regimens (g-level, angular velocity, duration, and repetition) will ameliorate the physiological and vestibular deconditioning associated with hypogravity during surface operation phases of a mission? **[ISS N/A, Lunar TBD, Mars TBD]**
14j	What artificial gravity exposure regimens (g-level, angular velocity, duration, and repetition) will ameliorate the physiological and vestibular deconditioning associated with hypogravity during transit phases of a mission in order to increase the capability to perform operational tasks after landing and throughout readaptation? **[ISS N/A, Lunar N/A, Mars TBD]**
14k	How can traditional clinical vestibular rehabilitation techniques be employed to usefully accelerate readaptation following g-transitions? **[ISS TBD, Lunar TBD, Mars TBD]**
14l	What objective assessment techniques can be used to determine crew readiness to return to normal activities following g-transitions? **[ISS TBD, Lunar TBD, Mars TBD]**

	14m	How can preflight or in-flight sensory-motor training or sensory aids improve post-landing postural and locomotor control and orthostatic tolerance? **[ISS TBD, Lunar TBD, Mars TBD]**
	14n	To what extent can crewmembers "learn how to learn" by adapting to surrogate sensory-motor rearrangements? **[ISS TBD, Lunar TBD, Mars TBD]**
	14o	What are the relative contributions of sensory-motor adaptation, neuromuscular deconditioning, and orthostatic intolerance to postflight neuro-motor coordination, ataxia, and locomotion difficulties? **[ISS TBD, Lunar TBD, Mars TBD]**
	14p	What posture, locomotion, and gaze deficits result from transition to lunar gravity (1/6-G) or Mars gravity (3/8-G)? **[ISS TBD, Lunar TBD, Mars TBD]**

Related Risks :	**Bone Loss**
	Accelerated Bone Loss and Fracture Risk
	Impaired Fracture Healing
	Injury to Joints and Intervertebral Structures
	Renal Stone Formation
	Cardiovascular Alterations
	Occurrence of Serious Cardiac Dysrhythmias
	Diminished Cardiac and Vascular Function
	Skeletal Muscle Alterations
	Reduced Muscle Mass, Strength, and Endurance
	Increased Susceptibility to Muscle Damage
	Sensory-Motor Adaptation
	Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing
	Motion Sickness
	Clinical Capabilities
	Monitoring and Prevention
	Ambulatory Care
	Rehabilitation on Mars
	Behavioral Health & Performance and Space Human Factors (Cognitive)
	Human Performance Failure Due to Neurobehavioral Problems
	Mismatch between Crew Cognitive Capabilities and Task Demands
	Radiation
	Acute and Late CNS Risks
	Space Human Factors Engineering
	Mismatch Between Crew Physical Capabilities and Task Demands

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Risk Title: Motion Sickness

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Sensory-Motor Adaptation
Risk Number :	15
Risk Description :	Crew work capacity, vigilance, and motivation may be impaired by motion sickness symptoms occurring during and after g transitions.
Context / Risk Factors :	This risk is influenced by individual susceptibilities, spacecraft size and room available for movement. It does not appear to be correlated with susceptibility to terrestrial motion sickness. Symptoms are repeatable but often attenuated from flight to flight.
Justification / Rationale :	Space motion sickness (SMS) is a common component of human space flight. For Shuttle crews, 70% experience symptoms for the first 2-4 days in 0-g, with emesis occurring in 10-20%, and many experience similar symptoms for hours to days after landing. Several crewmembers have remained symptomatic during flight for up to two weeks. Current anti-motion sickness treatment with IM Promethazine is highly effective and allows nominal space flight operations in spite of the high incidence of SMS. However, this drug has potentially significant side effects that may further complicate acute adaptation to space flight and prevent regular prophylactic use. Readaptation motion sickness may occur during entry and landing, prompting similar symptoms and possible impairment. In both situations, head movements, which may be required for normal operations, may be provocative.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 3 **Mars:** Priority 3
Current Countermeasures :	• Oral Promethazine/Ephedrine • Oral Scopolamine/Dexedrine (rare) • IM Promethazine • Head and body movement restriction, heads-up-display (HUD) for landing
Projected Countermeasures or Mitigations & other Deliverables:	• New administration methods of medicines for rapid, reliable relief with fewer side effects [CRL 6]

	• Techniques to quantify cognitive deficits as a side effect of medication [CRL 6] • Technique for providing a form of stroboscopic vision to reduce incidence of motion sickness [CRL 4]
Research & Technology Questions [With Mission Priority]:	(see table below)

No.	Question
15a	What are the physiological mechanisms that trigger vomiting in space motion sickness? **[ISS 1, Lunar 1, Mars 1]**
15b	What is the physiological basis of the emetic linkage between vestibular and emetic centers? **[ISS 2, Lunar 2, Mars 2]**
15c	What individual physiological and behavioral characteristics contribute to the large inter-individual differences in neurovestibular symptoms and signs? **[ISS 1, Lunar 1, Mars 1]**
15d	What individual physiological and behavioral characteristics will best predict susceptibility and adaptability? **[ISS 3, Lunar 3, Mars 3]**
15e	What is the physiological basis for context-specific-adaptation? **[ISS 1, Lunar 1, Mars 1]**
15f	To what extent can neurovestibular adaptation to weightlessness and/or artificial gravity take place in context-specific fashion, so crewmembers can be adapted to multiple environments and switch between them without suffering disorientation or motion sickness? **[ISS 3, Lunar 3, Mars 3]**
15g	What preflight training techniques (e.g., virtual reality simulations, parabolic flight) can be used to alleviate the risks of space motion sickness? **[ISS 4, Lunar 4, Mars 4]**
15h	What in-flight training techniques (e.g., virtual reality simulations, treadmill with vibration isolation system, artificial gravity) can be used to alleviate the risks of space motion sickness as astronauts land and (re)adapt to Earth, Moon, or Mars gravity? **[ISS 4, Lunar 4, Mars 4]**
15i	Is adaptation to the lunar gravity environment sufficient to reduce incidence of motion sickness upon return to Earth? **[ISS N/A, Lunar 4, Mars N/A]**
15j	How does susceptibility to motion sickness due to Coriolis forces and cross-coupled canal stimuli vary as a function of g-levels between 0-G and 1-G, and also on RPM, radius, and head orientation during AG? **[ISS N/A, Lunar 1, Mars 1]**
15k	What are the best methods for quantifying the symptoms and signs of motion sickness and associated performance decrements and drug side effects in a non-intrusive way? **[ISS 2, Lunar 2, Mars 2]**
15l	What better ways can be found to administer anti-motion sickness drugs to provide more rapid and reliable relief, with fewer objectionable side effects? **[ISS 3, Lunar 3, Mars 3]**
15m	Do scopolamine and promethazine prevent or impair sensory-motor adaptation to 0-G? **[ISS 4, Lunar 4, Mars 4]**
15n	What new drugs will more specifically prevent nausea, fatigue, memory and vigilance deficits without side effects? **[ISS 4, Lunar 4, Mars 4]**
15o	Can drugs be developed to effectively block the emetic linkage without unacceptable side effects? **[ISS 4, Lunar 4, Mars 4]**
15p	Can operationally practical, non-pharmacologic techniques be developed that are effective against motion sickness? **[ISS 4, Lunar 4, Mars 4]**
15q	Is lunar gravity (1/6-G) or Mars gravity (3/8-G) adequate to prevent all cases of motion sickness? **[ISS 4, Lunar 4, Mars 4]**

Related Risks :	**Sensory-Motor Adaptation**
	Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing

	Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation **Clinical Capabilities** Monitoring and Prevention Pharmacology of Space Medicine Delivery Ambulatory Care Rehabilitation on Mars **Behavioral Health & Performance and Space Human Factors (Cognitive)** Human Performance Failure Due to Poor Psychosocial Adaptation Human Performance Failure Due to Neurobehavioral Problems **Space Human Factors Engineering** Mismatch Between Crew Physical Capabilities and Task Demands
Important References :	Davis JR, JM Vanderploeg, et al. (1988) "Space motion sickness during 24 flights of the Space Shuttle." Aviat Space Environ. Med. 59: 1185-1189. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=3240221 Graybiel A, and Lackner JR. Treatment of severe motion sickness with antimotion sickness drug injections. Aviat Space and Environ Med. 58: 773-776, 1987. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=3632537 Guedry FE and AJ Benson. Coriolis cross-coupling effects: Disorienting and nauseogenic or not? Aviation, Space, and Environmental Medicine, 49(1): 29-35, 1978. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=304719 Lackner JR and Graybiel A. Head movements made in non-terrestrial force environments elicit motion sickness: implications for the etiology of space motion sickness. Aviat Space and Environ Med. 57: 443-448, 1986. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=3632537 Matsnev EI, IY Yakovleva, et al. (1983) "Space motion sickness: phenomenology, countermeasures, and mechanisms." Aviat Space and Environ Med. 54: 312-317. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=6847567 Baldwin, et. al. (1997) NASA Task Force on Countermeasures, Final Report. Neurovestibular Countermeasures Appendix E-26 Cowings PS. (1990) Autogenic-Feedback Training: A Preventive Method for Motion and Space Sickness. In: (G. Crampton (ed.). Motion and Space Sickness. Boca Raton Florida: CRC Press. Chapter 17, Pp.354-372 Oman CM, BK Lichtenberg et .al. (1990) Symptoms and signs of space motion sickness on Spacelab-1. Motion and Space Sickness. G. H. Crampton. Boca Raton, FL, CRC Press: 217-246. Reschke MF, JJ Bloomberg et al. (1994) Neurophysiological Aspects: Sensory and Sensory-Motor Function. Space Physiology and Medicine. A. E. Nicogossian, Lea and Febiger. Wood CD, Graybiel A. (1968). Evaluation of Sixteen Anti-motion Sickness Drugs Under Controlled Laboratory Conditions. Aerosp Med. 39:1341-4. Oman CM. (1990) "Motion sickness: a synthesis and evaluation of the sensory conflict theory." Can J Physiol Pharmacol. 68: 294-303.

Risk Title: Inadequate Nutrition

Crosscutting Area :	Human Health and Countermeasures (HHC)
Discipline :	Nutrition
Risk Number :	16
Risk Description :	Maintenance of astronaut health depends on a food system that provides all of the required nutrients.
Context / Risk Factors :	Nutritional requirements for space include fluids, macronutrients, micronutrients and other elements required to optimize health status. Requirements must take into account any changes in the sensory system that might influence taste, smell, intake, and the role that countermeasure- and space flight factor-induced alterations may have on nutrient requirements. This risk may be influenced by psychosocial factors, elevated stress and boredom, or compliance with diet.
Justification / Rationale :	Nutritional deficiencies may lead to an increased health risk as the duration of space flight increases. Inadequate micronutrient or vitamin intake could adversely affect crew health. Furthermore, adequate nutrition may play a role in counteracting the negative effects of space flight (e.g., radiation, immune deficits, and bone and muscle loss). While all long duration crewmembers have lost body mass, the cause of weight loss is not yet fully understood. For a Mars mission, there are additional challenges to provide a variety of fresh, palatable, and nutritious foods.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 3 **Mars:** Priority 2
Current Countermeasures :	• Provision of adequate diet through use of proper food system and vitamin supplements
Projected Countermeasures or Mitigations & other Deliverables:	• Improved dietary compliance and counseling [CRL 4] • Enhanced food system [CRL 4] • Diet and nutritional supplementation that ensures and/or enhances the effectiveness of other countermeasures [CRL 4] • Refined nutritional requirements [CRL 4] • Understanding and implementing an acceptable food system [CRL 4]

Research & Technology Questions [With Mission Priority]:

No.	Question
16a	What are the nutritional requirements for extended stay ISS missions, including (but not limited to): calories, protein, calcium, iron, antioxidants, iodine, vitamin D, sodium, potassium? **[ISS 1, Lunar 1, Mars 1]**
16b	What are the potential impacts of countermeasures on nutritional requirements or nutritional status? **[ISS 1, Lunar 1, Mars 1]**
16c	What are the decrements in nutritional status due to long-term LEO, lunar, and exploration missions? **[ISS 1, Lunar 1, Mars 1]**
16d	What are the means of monitoring nutritional status during the mission? **[ISS 3, Lunar 3, Mars 3]**
16e	What monitoring (biochemical, anthropometric, clinical assessments) during rehabilitation is required? **[ISS 3, Lunar 3, Mars 3]**
16f	What level of dietary counseling is needed for crewmembers during rehabilitation? **[ISS 3, Lunar 3, Mars 3]**
16g	Can general nutrition, or specific nutrient countermeasures, mitigate the negative effects of space flight on bone, muscle, cardiovascular and immune systems, and protect against damage from radiation? **[ISS 1, Lunar 1, Mars 1]**
16h	What is the role of adequate nutrition/weight maintenance on crew health (specifically bone, muscle and cardiovascular adaptation)? **[ISS 1, Lunar 2, Mars 1]**
16i	What level of dietary counseling is needed for crewmembers pre-flight? **[ISS 1, Lunar 2, Mars 1]**

	16j	How does on-orbit exercise affect nutritional requirements and vice versa? **[ISS 1, Lunar 2, Mars 1]**
	16k	Can general nutrition, or specific nutrient countermeasures, mitigate radiation-induced carcinogenesis or cataractogenesis? **[ISS 1, Lunar 1, Mars 1]**
	16l	Are there long-term effects of disease risk post-flight, and can nutritional countermeasures be preventative? **[ISS 1, Lunar 2, Mars 1]**
Related Risks :		**Bone Loss**
		Accelerated Bone Loss and Fracture Risk
		Impaired Fracture Healing
		Renal Stone Formation
		Cardiovascular Alterations
		Occurrence of Serious Cardiac Dysrhythmias
		Diminished Cardiac and Vascular Function
		Immunology & Infection
		Immune Dysfunction, Allergies and Autoimmunity
		Interaction of Space flight Factors, Infections and Malignancy
		Skeletal Muscle Alterations
		Reduced Muscle Mass, Strength, and Endurance
		Increased Susceptibility to Muscle Damage
		Clinical Capabilities
		Monitoring and Prevention
		Major Illness and Trauma
		Pharmacology of Space Medicine Delivery
		Ambulatory Care
		Rehabilitation on Mars
		Behavioral Health & Performance and Space Human Factors (Cognitive)
		Human Performance Failure Due to Poor Psychosocial Adaptation
		Radiation
		Carcinogenesis
		Acute and Late CNS Risks
		Chronic and Degenerative Tissue Risks
		Acute Radiation Risks
		Advanced Food Technology
		Maintain Food Quantity and Quality
		Advanced Life Support
		Provide and Maintain Bioregenerative Life Support Systems
		Provide and Recover Potable Water
Important References :		NASA Johnson Space Center. Nutritional Requirements for International Space Station Missions Up To 360 Days. JSC-28038; 1996.
		Nutrition. 18:793-936, 2002. (volume dedicated to nutrition and space, >20 articles)

Risk Title: Monitoring and Prevention

Crosscutting Area :	Autonomous Medical Care (AMC)
Discipline :	Clinical Capabilities
Risk Number :	17
Risk Description :	The risk of serious medical events may increase due to inadequate monitoring and prevention capabilities.
Context / Risk Factors :	This risk may be influenced by family history, medical history, and pre-flight or pre-mission screening.
Justification / Rationale :	The primary means to reduce the risk of life- and/or mission-threatening medical conditions is to prevent those conditions from happening through screening and preventive strategies. The second most effective means to reduce such risk is to monitor for medical conditions so that treatment can be implemented at an early stage. Autonomous monitoring and care strategies need to be validated in low earth orbit where support is assured. Because of increased distance and delay in communication, the medical monitoring support for a lunar mission will transition from predominately ground based to an autonomous system. For a mission to Mars, due to distance, delay in communication and no return capability, real time monitoring and medical support will be exclusively autonomous.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Annual and preflight comprehensive physical exams • In-flight examination, monitoring and care • Selection standards for space flight
Projected Countermeasures or Mitigations & other Deliverables:	• Additional screening criteria • Better in flight health monitoring capability • A more autonomous, reliable suite of medical diagnostic and therapeutic clinical care hardware and procedures [Lunar] [Mars]
Research & Technology Questions [With Mission Priority]:	(see table below)

No.	Question
	Health Tracking
17a	What are the key parameters for health screening and early detection? **[ISS 4, Lunar 2, Mars 1]**
17b	What resources and technologies are required for routine health monitoring, including examination, laboratory, imaging and adaptation for operation in reduced-G environments? **[ISS 4, Lunar 2, Mars 1]**
17c	What diagnostic imaging technologies and procedures need to be developed and/or adapted to support the primary, secondary and tertiary prevention of illness and injury? **[ISS 3, Lunar 2, Mars 1]**
17d	What parameters and sensors are needed to monitor health and performance in crewmembers performing EVA? **[ISS 4, Lunar 2, Mars 2]**
17e	What are the investigations needed to discriminate between terrestrial and space flight norms in order to allow early detection of illness and injury? **[ISS 3, Lunar 2, Mars 2]**
17f	What is space-normal physiology? **[ISS 4, Lunar 3, Mars 3]**
17g	What are the signs, symptoms or abnormal examination findings (including laboratory) associated with illness and injury in reduced-G? **[ISS TBD, Lunar TBD, Mars TBD]**
17h	How do alterations in space flight associated physiology interact across body systems? **[ISS 4, Lunar 3, Mars 3]**
17i	What are the appropriate informatics tools to automate crew health monitoring in order to free-up crew time (i.e. prompting screening and evaluations, off-nominal value detection, intelligent diagnostic work-up)? **[ISS 2, Lunar 1, Mars 1]**
	Prophylaxis/Disease Prevention

	17j	What are the ideal set of nutritional and medical prophylaxes, and primary and secondary preventive measures to reduce the risk of space illness (such as medical countermeasures for known conditions - e.g., bisphosphonates for loss of BMD)? **[ISS 3, Lunar 2, Mars 2]**
	17k	What are the primary, secondary, and tertiary prevention strategies needed to mitigate the risk of anticipated environmental exposures to radiation and toxic substances (i.e. shielding, nutritional and medical prophylaxis such as agents to augment cellular defenses, immune surveillance, etc.)? **[ISS 2, Lunar 1, Mars 1]**
	17l	What are the essential technologies, resources, procedures, skills and training necessary to provide effective primary prevention strategies to mitigate each of the conditions listed in the SMCCB-approved Space Medicine Condition List (catalogued in the online Patient Condition Database)? **[ISS 4, Lunar 3, Mars 2]**
	17m	What are the essential technologies, resources, procedures, skills and training necessary to provide effective secondary prevention strategies to mitigate each of the conditions listed in the SMCCB-approved Space Medicine Condition List (catalogued in the online Patient Condition Database)? **[ISS 4, Lunar 3, Mars 2]**

Related Risks :	**Bone Loss**
	Accelerated Bone Loss and Fracture Risk
	Injury to Joints and Intervertebral Structures
	Renal Stone Formation
	Cardiovascular Alterations
	Occurrence of Serious Cardiac Dysrhythmias
	Diminished Cardiac and Vascular Function
	Environmental Health
	Define Acceptable Limits for Contaminants in Air and Water
	Immunology & Infection
	Immune Dysfunction, Allergies and Autoimmunity
	Interaction of Space flight Factors, Infections and Malignancy
	Alterations in Microbes and Host Interactions
	Skeletal Muscle Alterations
	Reduced Muscle Mass, Strength, and Endurance
	Increased Susceptibility to Muscle Damage
	Sensory-Motor Adaptation
	Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing
	Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation
	Motion Sickness
	Nutrition
	Inadequate Nutrition
	Clinical Capabilities
	Major Illness and Trauma
	Pharmacology of Space Medicine Delivery
	Ambulatory Care
	Rehabilitation on Mars
	Medical Informatics, Technologies, and Support Systems

	Medical Skill Training and Maintenance **Behavioral Health & Performance and Space Human Factors (Cognitive)** Human Performance Failure Due to Poor Psychosocial Adaptation Human Performance Failure Due to Neurobehavioral Problems Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems **Radiation** Acute and Late CNS Risks Chronic and Degenerative Tissue Risks Acute Radiation Risks **Advanced Environmental Monitoring & Control** Monitor Air Quality Monitor External Environment Monitor Water Quality Monitor Surfaces, Food, and Soil **Advanced Extravehicular Activity** Provide Space Suits and Portable Life Support Systems
Important References :	

Risk Title: Major Illness and Trauma

Crosscutting Area :	Autonomous Medical Care (AMC)
Discipline :	Clinical Capabilities
Risk Number :	18
Risk Description :	Lack of capability to treat major illness and injuries increases the risk to crew health and mission.
Context / Risk Factors :	Risk of trauma will vary according to mission activities and risk of illness will increase with mission duration. Equipment and activities are designed to minimize risk of injury.
Justification / Rationale :	For ISS, the risk for major trauma is considered low. For missions to the Moon and Mars, there is a significant risk of trauma associated with EVA. There is a risk for development of major illness.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 1 **Mars:** Priority 1
Current Countermeasures :	• Return to Earth for definitive care • On-board treatment capability (ventilator, IV fluids, medications, etc.) • Preventive measures
Projected Countermeasures or Mitigations & other Deliverables:	• Autonomous capabilities for monitoring and treatment of identified conditions, because quick return is not an option for missions to the Moon and Mars
Research & Technology Questions [With Mission Priority]:	see table below

No.	Question
18a	What are the essential technologies, resources, procedures, skills, and training necessary to provide effective prevention strategies to mitigate each of the conditions listed in the SMCCB-approved Space Medicine Condition List (catalogued in the online Patient Condition Database)? **[ISS 3, Lunar 1, Mars 1]**
	Major Illness Diagnosis

	18b	What are the technologies for employing decision support techniques for diagnostic assistance of the crew medical personnel, emphasizing autonomy in decision-making from ground resources and based on known space flight illnesses and injuries and expedition analog experience? **[ISS 2, Lunar 1, Mars 1]**
	18c	What are the appropriate roles and resources required for telemedical consultation for the diagnosis and management of major illnesses? **[ISS 3, Lunar 2, Mars 1]**
	18d	What resources are required for telemedical consultation, diagnosis, and management of major trauma? **[ISS 3, Lunar 2, Mars 1]**
		Major Illness Treatment
	18e	What are the resources, procedures, and technologies required for treatment of major illnesses, emphasizing autonomy from ground resources and based on known space flight illnesses, injuries, and expedition analog experience, and how might they be adapted for reduced-G operations? **[ISS 2, Lunar 1, Mars 1]**
	18f	What are the resources and procedures needed to perform basic and advanced management of trauma? **[ISS 3, Lunar 1, Mars 1]**
	18g	What are the specific techniques, resources, protocols, training curricula, skills, and equipment (technology) necessary to implement palliative care protocols for in-flight use? **[ISS 4, Lunar 2, Mars 1]**
	18h	What are effective management strategies for chronic pain in reduced-G (pharmacologic and non-pharmacologic)? **[ISS TBD, Lunar TBD, Mars TBD]**
	18i	What procedures and protocols are necessary for rehabilitation after an acute medical illness or trauma? **[ISS 4, Lunar 3, Mars 1]**
	18j	What are effective management strategies for acute pain in reduced-G (pharmacologic and non-pharmacologic)? **[ISS TBD, Lunar TBD, Mars TBD]**
	18k	What are the nutritional requirements for adequate red cell production in microgravity? What are the contributory factors and how do they inter-relate in the development of space anemia (radiation, unloading, nutrition, fluid shift, changes in sex hormones, etc.)? **[ISS 2, Lunar 2, Mars 2]**
	18l	How can aplastic anemia be treated during space missions? **[ISS 5, Lunar 5, Mars 3]**
	18m	What are the appropriate synergistic and alternative management strategies for reducing the morbidity of major illnesses during space flight? **[ISS TBD, Lunar TBD, Mars TBD]**
	18n	What is the most effective means of conducting life support operations in the space flight milieu, to include identification and modification of the resources and procedures for reduced-G? **[ISS 3, Lunar 2, Mars 1]**
	18o	What are the optimal resources and procedures for post-resuscitation management of the ill/injured crewmember and modify for reduced-G operations? **[ISS 2, Lunar 1, Mars 1]**
		Decompression Illness (DCS) & Other Environmental Illness
	18p	What is the most effective pre-EVA Decompression Sickness (DCS) prevention strategy to include pre-breathe with various gases, exercise and other medical measures? **[ISS 5, Lunar TBD, Mars TBD]**
	18q	What are the appropriate screening procedures to minimize predispositions for DCS? **[ISS 4, Lunar TBD, Mars TBD]**
	18r	What are the resources and techniques for early diagnosis of DCS signs and symptoms, including the use of Doppler U/S and other bubble detection technologies? **[ISS 4, Lunar TBD, Mars TBD]**
	18s	What are the best methods for predicting DCS risk and for reducing the risk, based on understanding of the physiological mechanism for bubble formation and propagation, employing best available knowledge from flight and analog environment experience? **[ISS 4, Lunar TBD, Mars TBD]**

	18t	What are the most effective yet safe, and energy- and space-efficient means of managing DCS in the space flight milieu, including the use of hyperbaric oxygen delivery and other promising technology, and how might they be adapted for reduced-G operations? **[ISS 3, Lunar 2, Mars 1]**
	18u	What is the actual risk of space-related DCS? (de novo physiological causes and acute environmental insult - e.g., leaking module or damaged EMU etc.) **[ISS 3, Lunar 3, Mars 3]**
	18v	What are the operational and medical impacts of off-nominal performance of DCS countermeasures? **[ISS 4, Lunar 3, Mars 3]**
	18w	What are the risk factors that can increase the likelihood of DCS, such as the presence of Patent Foramen Ovale (PFO)? **[ISS 4, Lunar 3, Mars 2]**
	18x	What is the likelihood of surviving an acute environmental insult severe enough to cause damage to the vehicle or spacesuit? **[ISS 2, Lunar 2, Mars 2]**
	18y	Is it possible and what are the DCS risk mitigation options for interplanetary EVA (e.g., moon and Mars) given that a tri-gas breathing mixture including argon is present? **[ISS 4, Lunar 4, Mars 4]**
	18z	What is the role of individual susceptibility, age and gender on the risk of DCS during NASA operations involving decompression? **[ISS 4, Lunar 3, Mars 3]**
	18aa	What are the available and new technologies needed to provide hyperbaric treatment options on the ISS and future habitats (or vehicles) beyond LEO (e.g., on the moon or Mars)? **[ISS 3, Lunar 2, Mars 1]**
	18ab	What is the correlation between the detection/existence of gas phase creation in the bloodstream and development of clinically significant DCS? **[ISS 4, Lunar 3, Mars 3]**
	18ac	What are the monitoring, prevention, and treatment methods for clinical effects of acute, excessive, radiation exposure? **[ISS 3, Lunar 2, Mars 1]**
	18ad	What are the signs and symptoms secondary to radiation and toxic chemical exposure in reduced-G environments? **[ISS 2, Lunar 1, Mars 1]**
	18ae	What are the resources and procedures for the mitigation of toxic exposures? **[ISS 3, Lunar 1, Mars 1]**
	18af	What primary prevention strategies (such as crew screening and selection criteria) should be developed and implemented to identify individuals who are at increased risk for developing hypersensitivity or allergies to space flight compounds, exposures, or payloads? **[ISS 3, Lunar 2, Mars 2]**
	18ag	What secondary prevention strategies (i.e. countermeasures) should be developed and implemented to prevent adverse reactions to toxic exposures (e.g., sleep, nutrition, medication, stress reduction, shielding, protective equipment, etc.)? **[ISS 3, Lunar 2, Mars 2]**
	Surgical Management	
	18ah	What resources and procedures are needed for the surgical management of major illness, injury, and trauma? **[ISS 3, Lunar 1, Mars 1]**
	18ai	What are the appropriate roles and resources required for telemedical consultation for the surgical management of major illnesses? **[ISS 3, Lunar 2, Mars 1]**
	18aj	What are the issues surrounding wound care, and how are they best resolved? **[ISS 4, Lunar 2, Mars 2]**
	18ak	What are effective regional and local anesthesia strategies in reduced G? **[ISS TBD, Lunar TBD, Mars TBD]**
	18al	What methods and new technologies are needed for blood replacement therapy in space? **[ISS 3, Lunar 2, Mars 1]**
	Medical Waste Management	
	18am	What are the most effective means of management and disposal of medical waste within the surgical milieu? **[ISS 2, Lunar 1, Mars 1]**
Related Risks :	**Bone Loss**	

	Accelerated Bone Loss and Fracture Risk Impaired Fracture Healing Renal Stone Formation **Cardiovascular Alterations** Occurrence of Serious Cardiac Dysrhythmias Diminished Cardiac and Vascular Function **Environmental Health** Define Acceptable Limits for Contaminants in Air and Water **Immunology & Infection** Immune Dysfunction, Allergies and Autoimmunity Interaction of Space flight Factors, Infections and Malignancy **Clinical Capabilities** Monitoring and Prevention Pharmacology of Space Medicine Delivery Ambulatory Care Rehabilitation on Mars Medical Informatics, Technologies, and Support Systems Medical Skill Training and Maintenance **Behavioral Health & Performance and Space Human Factors (Cognitive)** Human Performance Failure Due to Neurobehavioral Problems **Radiation** Carcinogenesis Acute and Late CNS Risks Chronic and Degenerative Tissue Risks Acute Radiation Risks **Advanced Extravehicular Activity** Provide Space Suits and Portable Life Support Systems
Important References :	

Risk Title: Pharmacology of Space Medicine Delivery

Crosscutting Area :	Autonomous Medical Care (AMC)
Discipline :	Clinical Capabilities
Risk Number :	19
Risk Description :	Diminished drug efficacy due to reduced shelf life and alterations in pharmacodynamics and pharmacokinetics may compromise treatment capabilities.
Context / Risk Factors :	Degraded shelf life may be related to the space radiation environment and other microgravity factors. This risk may be influenced by limited or no re-supply, microgravity, or the radiation environment.
Justification / Rationale :	Medications returned from ISS have been shown to have decreased potency beyond what is expected. Microgravity pharmacokinetics is not well understood.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 2 **Mars:** Priority 1
Current	

<table>
<tr><td>Countermeasures :</td><td>Re-supply of medications on ISS</td></tr>
<tr><td>Projected Countermeasures or Mitigations & other Deliverables:</td><td>Shielding of medications from space radiation
Alteration in dose and formulation of medication</td></tr>
<tr><td>Research & Technology Questions [With Mission Priority]:</td><td>
<table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td colspan="2">Pharmacodynamics/Pharmacokinetics</td></tr>
<tr><td>19a</td><td>What are the effects of space flight and reduced-G on the absorption, distribution, metabolism, clearance, excretion, clinical efficacy, side effects and drug interactions for medications used in primary, secondary and tertiary prevention of conditions stated in the Space Medicine Condition List? [ISS 2, Lunar 2, Mars 1]</td></tr>
<tr><td>19b</td><td>How should the crew and medical team be trained and prepared to recognize and deal with side effects and interaction effects of commonly used medications? [ISS 3, Lunar 3, Mars 2]</td></tr>
<tr><td>19c</td><td>What diagnostic, therapeutic and laboratory technologies are necessary to predict (model) and manage medication side effects, interactions and toxicity during space flight? [ISS 3, Lunar 3, Mars 3]</td></tr>
<tr><td>19d</td><td>What effect does space adaptation have on drug bio-availability and how can efficacy be enhanced? [ISS 2, Lunar 2, Mars 1]</td></tr>
<tr><td colspan="2">Drug Stowage/Utilization/Replenishment</td></tr>
<tr><td>19e</td><td>What is the effect of long-duration space flight on drug stability, and what measures can be employed to extend the duration of drug efficacy? [ISS 3, Lunar 1, Mars 1]</td></tr>
<tr><td>19f</td><td>What are the appropriate on-orbit/on-station means of drug and intravenous (IV) fluid replenishment appropriate for space operations? [ISS 3, Lunar 1, Mars 1]</td></tr>
<tr><td>19g</td><td>What are biomedical models for drug efficacy? [ISS 4, Lunar 3, Mars 3]</td></tr>
<tr><td colspan="2">Drug Use Optimization</td></tr>
<tr><td>19h</td><td>What are the optimal dosages and routes of administration for space flight/reduced-G clinical effectiveness? [ISS 3, Lunar 2, Mars 2]</td></tr>
<tr><td>19i</td><td>What are efficient means of monitoring drug levels for therapeutic effect and toxicity to minimize cross-reaction and negative synergy? [ISS 4, Lunar 3, Mars 3]</td></tr>
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<tr><td>Related Risks :</td><td>
<table>
<tr><td>Bone Loss</td></tr>
<tr><td>Accelerated Bone Loss and Fracture Risk</td></tr>
<tr><td>Impaired Fracture Healing</td></tr>
<tr><td>Renal Stone Formation</td></tr>
<tr><td>Cardiovascular Alterations</td></tr>
<tr><td>Occurrence of Serious Cardiac Dysrhythmias</td></tr>
<tr><td>Diminished Cardiac and Vascular Function</td></tr>
<tr><td>Immunology & Infection</td></tr>
<tr><td>Immune Dysfunction, Allergies and Autoimmunity</td></tr>
<tr><td>Interaction of Space flight Factors, Infections and Malignancy</td></tr>
<tr><td>Skeletal Muscle Alterations</td></tr>
<tr><td>Reduced Muscle Mass, Strength, and Endurance</td></tr>
<tr><td>Sensory-Motor Adaptation</td></tr>
<tr><td>Motion Sickness</td></tr>
<tr><td>Clinical Capabilities</td></tr>
<tr><td>Monitoring and Prevention</td></tr>
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	Major Illness and Trauma Ambulatory Care Rehabilitation on Mars Medical Informatics, Technologies, and Support Systems Medical Skill Training and Maintenance **Behavioral Health & Performance and Space Human Factors (Cognitive)** Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems **Radiation** Chronic and Degenerative Tissue Risks
Important References :	

Risk Title: Ambulatory Care

Crosscutting Area :	Autonomous Medical Care (AMC)
Discipline :	Clinical Capabilities
Risk Number :	20
Risk Description :	Impaired performance and increased risk to crew health and mission may occur due to lack of capability to diagnose and treat minor illnesses.
Context / Risk Factors :	Risks may vary depending on mission activities.
Justification / Rationale :	Minor illnesses and injuries have been documented during space flight. Capability to diagnose and treat minor medical conditions will ensure crew health remains good and the mission is not impacted. Current ISS capability is acceptable for future ISS missions
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 3 **Mars:** Priority 2
Current Countermeasures :	• Crew Screening • Crew training to recognize and treat medical conditions • Design of equipment and procedures to reduce the likelihood of injury • Medical kits with capability to diagnose and treat minor illnesses and injuries • Limited telemedicine capability • Real-time ground communication with medical experts
Projected Countermeasures or Mitigations & other Deliverables:	• More extensive medical kit • More extensive telemedicine capability • On board autonomous medical diagnostic and therapeutic aids
Research & Technology Questions [With Mission Priority]:	

No.	Question
	Minor Illness Diagnosis
20a	What are the resources for establishing the diagnosis of minor illnesses, emphasizing autonomous decision-making, based on known space flight illnesses, injuries, and expedition analogs? How might they be adapted to reduced-G operations? **[ISS 4, Lunar 2, Mars 1]**
20b	What are the appropriate roles and resources required for telemedical consultation for the diagnosis and management of minor illnesses? **[ISS 4, Lunar 3, Mars 2]**
	Minor Illness Management

	20c — What are the resources and procedures required for treatment of minor illnesses, emphasizing autonomy from ground resources and based on known space flight illnesses and injuries and expedition analog experience, and how might they be adapted for reduced-G operations? **[ISS 4, Lunar 3, Mars 2]** 20d — What are the appropriate synergistic and alternative management strategies for reducing the morbidity of minor illnesses during space flight? **[ISS TBD, Lunar TBD, Mars TBD]** **Minor Trauma Management** 20e — What are the resources and procedures required for the treatment of minor trauma, emphasizing autonomous decision-making, based on known space flight illnesses, injuries, and expedition analogs? How might they be adapted to reduced-G operations? **[ISS 3, Lunar 1, Mars 1]**
Related Risks :	**Bone Loss** Renal Stone Formation **Cardiovascular Alterations** Diminished Cardiac and Vascular Function **Immunology & Infection** Immune Dysfunction, Allergies and Autoimmunity Interaction of Space flight Factors, Infections and Malignancy **Skeletal Muscle Alterations** Increased Susceptibility to Muscle Damage **Sensory-Motor Adaptation** Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation Motion Sickness **Clinical Capabilities** Monitoring and Prevention Major Illness and Trauma Pharmacology of Space Medicine Delivery Rehabilitation on Mars Medical Informatics, Technologies, and Support Systems Medical Skill Training and Maintenance **Behavioral Health & Performance and Space Human Factors (Cognitive)** Human Performance Failure Due to Poor Psychosocial Adaptation Human Performance Failure Due to Neurobehavioral Problems Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems **Advanced Extravehicular Activity** Provide Space Suits and Portable Life Support Systems
Important References :	

Risk Title: Rehabilitation on Mars

Crosscutting Area :	Autonomous Medical Care (AMC)

Discipline :	Clinical Capabilities
Risk Number :	21
Risk Description :	Crew capability to function after landing on Mars may be compromised due to space flight deconditioning and lack of a remote, self-administered, rehabilitation program.
Context / Risk Factors :	This risk may be influenced by sensory neural alterations and ability to autonomously perform exercise program. This assumes functioning exercise hardware.
Justification / Rationale :	This risk is unique to an exploration mission to Mars. Significant deconditioning can occur during the transit to Mars and the crew must be able to self-administer a rehabilitation program en route and once they arrive at Mars so that they can function as needed.
Risk Rating :	**ISS:** N/A **Lunar:** N/A **Mars:** Priority 1
Current Countermeasures :	• Ground rehabilitation program and facilities [Mars] • In flight exercise [Mars] • Pre-flight conditioning [Mars]
Projected Countermeasures or Mitigations & other Deliverables:	• Countermeasures to neurovestibular effects [Mars] • Improved exercise protocols [Mars] • Autonomous medical monitoring capability [Mars] • Structured, self-administered rehabilitation program (physical and psychological) [Mars]
Research & Technology Questions [With Mission Priority]:	(see table below)

No.	Question
21a	What are the primary, secondary and tertiary preventive strategies needed to ensure post-landing performance for a Mars mission? **[ISS N/A, Lunar N/A, Mars 1]**
21b	What are the essential technologies, resources, protocols, skills and training necessary for post landing rehabilitation (including psychological, cardiovascular, neurosensory, musculoskeletal and nutritional)? **[ISS N/A, Lunar N/A, Mars 1]**

Related Risks :

Bone Loss
Accelerated Bone Loss and Fracture Risk
Impaired Fracture Healing
Injury to Joints and Intervertebral Structures
Renal Stone Formation
Cardiovascular Alterations
Occurrence of Serious Cardiac Dysrhythmias
Diminished Cardiac and Vascular Function
Immunology & Infection
Immune Dysfunction, Allergies and Autoimmunity
Interaction of Space flight Factors, Infections and Malignancy
Skeletal Muscle Alterations
Increased Susceptibility to Muscle Damage
Sensory-Motor Adaptation
Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing
Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation
Motion Sickness

	Nutrition Inadequate Nutrition **Clinical Capabilities** Monitoring and Prevention Major Illness and Trauma Pharmacology of Space Medicine Delivery Ambulatory Care Medical Informatics, Technologies, and Support Systems Medical Skill Training and Maintenance **Behavioral Health & Performance and Space Human Factors (Cognitive)** Human Performance Failure Due to Poor Psychosocial Adaptation Human Performance Failure Due to Neurobehavioral Problems Mismatch between Crew Cognitive Capabilities and Task Demands Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems **Radiation** Acute and Late CNS Risks Acute Radiation Risks
Important References :	

Risk Title: Medical Informatics, Technologies, and Support Systems

Crosscutting Area :	Autonomous Medical Care (AMC)
Discipline :	Clinical Capabilities
Risk Number :	22
Risk Description :	Limited communication capability during space flight results in the compromised ability to provide medical care, and may have adverse consequences for crew health.
Context / Risk Factors :	Risk will be exacerbated by lack of recent training, limited communication capability, and lack of real-time ground support.
Justification / Rationale :	Lack of real-time ground support due to limited communication and limited telemedical capability necessitates reliable, efficacious informatics capability and support. This is low priority for ISS, moderate priority for a lunar mission, and high priority for a Mars mission.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Limited telemedicine capability • On-board computer based training • Real-time ground support • Periodic on-orbit contingency drills • Medical checklist and preflight training
Projected Countermeasures or Mitigations & other Deliverables:	• Development of autonomous medical support systems

Research & Technology Questions [With Mission Priority]:	<table><tr><th>No.</th><th>Question</th></tr><tr><td>22a</td><td>What decision support technologies are needed to support clinical care? **[ISS 4, Lunar 2, Mars 1]**</td></tr><tr><td>22b</td><td>What informatics systems and technology are needed, both for crew and ground support, to optimize medical care? **[ISS 3, Lunar 1, Mars 1]**</td></tr><tr><td>22c</td><td>What are the impacts of communication latency on the ability to provide primary, secondary and tertiary prevention during space flight? **[ISS 4, Lunar 4, Mars 1]**</td></tr></table>
Related Risks :	<table><tr><td>**Clinical Capabilities**</td></tr><tr><td>Monitoring and Prevention</td></tr><tr><td>Major Illness and Trauma</td></tr><tr><td>Pharmacology of Space Medicine Delivery</td></tr><tr><td>Ambulatory Care</td></tr><tr><td>Rehabilitation on Mars</td></tr><tr><td>Medical Skill Training and Maintenance</td></tr><tr><td>**Advanced Extravehicular Activity**</td></tr><tr><td>Provide Space Suits and Portable Life Support Systems</td></tr><tr><td>**Space Human Factors Engineering**</td></tr><tr><td>Poorly Integrated Ground, Crew, and Automation Functions</td></tr></table>
Important References :	

Risk Title: Medical Skill Training and Maintenance

Crosscutting Area :	Autonomous Medical Care (AMC)
Discipline :	Clinical Capabilities
Risk Number :	23
Risk Description :	Inability to perform required medical procedures may result from inadequate crew medical skills or medical training.
Context / Risk Factors :	A physician may be required on a Mars crew.
Justification / Rationale :	Illness and injuries are likely to occur. The crew must be able to diagnose and treat a variety of conditions. Different mission scenarios will require a different level of expertise and autonomy. For ISS, real time ground support is available and there is return capability. For a lunar mission the crew must be trained more extensively because of reduced availability of ground support. The Mars crew will require extensive training and support hardware because of lack of ground support and return capability.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Limited telemedicine capability • On-board computer based training • Crew Medical Officer (CMO) training • Real-time ground support • Periodic on-orbit contingency drills
Projected Countermeasures or Mitigations & other	• More extensive medical training, including medical and surgical capabilities • Autonomous medical support systems

<table>
<tr><td>Deliverables:</td><td></td></tr>
<tr><td>Research & Technology Questions [With Mission Priority]:</td><td>
<table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td>23a</td><td>What are the necessary clinical skills/knowledge for a space medicine physician? [ISS 4, Lunar 1, Mars 1]</td></tr>
<tr><td>23b</td><td>How can the clinical skills and knowledge of space medical care providers be maintained during missions? [ISS 2, Lunar 2, Mars 1]</td></tr>
<tr><td>23c</td><td>What is the optimum crew complement (size, skill sets, etc.) to provide the appropriate medical care for the primary, secondary and tertiary care for the conditions in the Space Medicine Condition List? [ISS 4, Lunar 3, Mars 1]</td></tr>
<tr><td>23d</td><td>What techniques can be used to train and maintain the skills of the crew medical personnel to perform specific medical procedures when needed? [ISS 3, Lunar 1, Mars 1]</td></tr>
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<tr><td>Related Risks :</td><td>
<table>
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<tr><td>Medical Informatics, Technologies, and Support Systems</td></tr>
<tr><td>Behavioral Health & Performance and Space Human Factors (Cognitive)</td></tr>
<tr><td>Mismatch between Crew Cognitive Capabilities and Task Demands</td></tr>
<tr><td>Space Human Factors Engineering</td></tr>
<tr><td>Poorly Integrated Ground, Crew, and Automation Functions</td></tr>
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<tr><td>Important References :</td><td></td></tr>
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Risk Title: Human Performance Failure Due to Poor Psychosocial Adaptation

Crosscutting Area :	Behavioral Health and Performance (BHP)
Discipline :	Behavioral Health & Performance and Space Human Factors (Cognitive)
Risk Number :	24
Risk Description :	Human performance failure may occur due to problems associated with adapting to the space environment, interpersonal relationships, group dynamics, team cohesiveness, and pre-mission preparation.
Context / Risk Factors :	The isolated and confined nature of space flight, along with its potential hazards, pose human performance related challenges. This risk may be influenced by boredom with available food, crew autonomy and increased reliance on each other, crowding, distance from family and friends, duration of flight, incompatible crewmembers, interpersonal tensions, mechanical breakdowns, poor communications, scheduling constraints and requirements, sleep disturbances, or social isolation.
Justification / Rationale :	Moderate likelihood/high consequence risk with low risk mitigation status. Serious interpersonal conflicts have occurred in space flight. The failure of flight crews to cooperate and work effectively with each other or with flight controllers has been a periodic problem in both US and Russian space flight programs. Interpersonal distrust, dislike, misunderstanding and poor communication have led to potentially dangerous situations, such as crewmembers refusing to speak to one another during critical operations, or withdrawing from voice communications with ground controllers. Such problems of group cohesiveness have a high likelihood of occurrence in prolonged space flight and if not mitigated through prevention or intervention, they will pose grave risks to the mission. Lack of adequate personnel selection, team assembly, or training has been found to have deleterious effects on work performance in organizational research studies. The duration and distance of a Mars mission significantly increases this risk. The distance also reduces countermeasure options and increases the need for autonomous behavioral health support systems.

Risk Rating :	**ISS:** Priority 1 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Language and cultural training, • Personal in-flight communications with Earth • Post-flight debriefs • Pre-flight training and teambuilding, • Self-report monitoring of adaptation during mission with private psychological conference • Select-out criteria • In-flight and preflight psychological support
Projected Countermeasures or Mitigations & other Deliverables:	• Development of individual performance enhancement plan for each crewmember [CRL 1] • Individual and team selection for long-duration missions [CRL 3] • Monitoring & early detection of adaptation problems [CRL 3] • Predictive model of adaptability to long-duration missions [CRL 1] • Select-in criteria
Research & Technology Questions [With Mission Priority]:	

No.	Question
24a	What are the fundamental behavioral and social stressors during long-duration missions that will most likely affect crew performance, both individual and team, and how can they be studied for elimination or accomodation in Earth analogue environments? **[ISS 1, Lunar 1, Mars 1]**
24b	What factors contribute to the breakdown of individual/team performance and mission support coordination with regard to scheduling, prioritization of work activities, and control of timelines? **[ISS 1, Lunar 1, Mars 1]**
24c	What behaviors, experiences, personality traits and leadership styles in crewmembers most contribute to optimal performance? How are these factors related to performance of individuals and teams? **[ISS 2, Lunar 2, Mars 2]**
24d	What criteria can be identified during the selection process and be used to select and assemble the best teams for long-duration missions? **[ISS 2, Lunar 2, Mars 2]**
24e	What factors in crew design, composition, dynamics and size will best enhance the crew's ability to live and work in the space environment? How are these factors different from shorter duration missions? **[ISS 2, Lunar 2, Mars 2]**
24f	How can attitudes and behaviors of agency management, ground controllers, crewmembers and their families be modified to maintain and improve individual and group performance? **[ISS 2, Lunar 2, Mars 2]**

Related Risks :

Nutrition
Inadequate Nutrition
Clinical Capabilities
Monitoring and Prevention
Ambulatory Care
Behavioral Health & Performance and Space Human Factors (Cognitive)
Human Performance Failure Due to Neurobehavioral Problems
Mismatch between Crew Cognitive Capabilities and Task Demands
Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems
Radiation

	Acute and Late CNS Risks **Advanced Food Technology** Maintain Food Quantity and Quality **Space Human Factors Engineering** Poorly Integrated Ground, Crew, and Automation Functions
Important References :	Kanas N. Psychiatric issues affecting long-duration space missions. Aviation Space & Environmental Medicine. 69:1211-1216, 1998. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=9856550 McCormick IA, Taylor AJ, Rivolier J, & Cazes G. (1985). A psychometric study of stress and coping during the International Biomedical Expedition to the Antarctic (IBEA). J Human Stress. 11(4), 150-156. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=3843117 Palinkas LA, Gunderson EK, Holland AW, Miller C, & Johnson JC. (2000) Predictors of behavior and performance in extreme environments: the Antarctic space analogue program. Aviat Space Environ Med. 71(6): 619-625. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=10870821 Taylor AJ. (1998). Psychological adaptation to the polar environment. Int J Circumpolar Health. 57(1): 56-68. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=9567576 Wood JA, Hysong SJ, Lugg DJ, & Harm DL. (2000) Is it really so bad? A comparison of positive and negative experiences in Antarctic winter stations. Environment and Behavior. 32(1): 85-110. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11542948 Wood JA, Lugg DJ, Hysong SJ, Eksuzian DJ, & Harm DL. (1999) Psychological changes in hundred-day remote Antarctic field groups. Environment and Behavior. 31(3): 299-337. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11542387 Connors MM, Harrison AA, and Faren RA. Living Aloft: Human requirements for extended space flight. NASA SP-483, Washington, D.C., National Aeronautics and Space Administration, 1985. Harrison AA, Clearwater YA, and McKay CA. (eds), From Antarctica to outer space: Life in Isolation and Confinement. NY, NY Springer-Verlag, 1991. Palinkas LA. (1991) Effects of physical and social environments on the health and well-being of Antarctic winter-over personnel. Environment & Behavior. 23(6); 782-799. Palinkas LA, & Gunderson EK. (1988) Applied anthropology on the ice: A multidisciplinary perspective on health and adaptation in Antarctica (No. 88-21). San Diego: Naval Health Research Center.

Risk Title: Human Performance Failure Due to Neurobehavioral Problems

Crosscutting Area :	Behavioral Health and Performance (BHP)
Discipline :	Behavioral Health & Performance and Space Human Factors (Cognitive)
Risk Number :	25
Risk Description :	Human performance failure may occur due to conditions such as depression, anxiety, or other psychiatric and cognitive problems.

Context / Risk Factors :	For long duration missions, inadequate countermeasures or failure of early detection of behavioral health problems could result in more severe psychiatric problems. This risk may be influenced by clinical capabilities, concern about health or loss of life or mission failure, lack of privacy, differential vulnerability to neurobehavioral problems, duration of flight, environmental health, loneliness and worry about family, nutrition, prolonged isolation and confinement, or trauma from an unexpected event.
Justification / Rationale :	Although infrequent, serious neurobehavioral problems involving stress and depression have occurred in space flight, especially during long-duration missions. In some of these instances, the distress has contributed to performance errors. In other instances, emotional problems led to changes in motivation, diet, sleep and exercise-all critical to behavioral and physical health in-flight. No matter how prepared crews are for long-duration flights, the US and Russian experiences reveal that at least some subset of astronauts will experience problems with their behavioral health, which will negatively affect their performance and reliability, posing risks both to individual crewmembers and to the mission. The IOM report, Safe Passages, notes that Earth analogue studies show an incidence rate ranging from 3-13 percent per person per year. The report transposes these figures to 6-7 person crew on a 3-year mission to determine that there is a significant likelihood of psychiatric problems emerging (p.106).
Risk Rating :	**ISS:** Priority 1 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Crew medical officer behavioral medicine training pre-flight • Detection at the time of failure • Emergency response protocol on-orbit • Individual pre-flight and post-flight evaluations • Medication therapy, including during space flight • Opportunity for crewmembers to communicate with crew medical officer or health provider on ground • Select-in and select-out criteria • Self monitoring of cognition on-orbit and post-flight • Self-report monitoring during mission with private psychological conference
Projected Countermeasures or Mitigations & other Deliverables:	• Greater interaction and observation by behavioral specialist during astronaut professional training [CRL 4] • Improved ability to safely and effectively manage an uncooperative crewmember during mission [CRL 3] • Improved capability for remote diagnosis [CRL 3] • Improved diagnostic cognitive self-assessment [CRL 3] • Individualized treatment algorithm developed pre-flight [CRL 5] • On-board information technologies as astronaut aids for management of stress reactions and cognitive or emotional problems [CRL 3] • On-board modalities of therapy [CRL 4] • On-board unobtrusive technologies as astronaut aids for valid detection of stress reactions and cognitive or emotional problems [CRL 3] • Predictive model for risk of neurobehavioral illness in-flight [CRL 3] • Self monitoring of mood pre-flight, in-flight and post-flight [CRL 4] • Updated behavioral medicine aeromedical standards [CRL 4]

Research & Technology Questions [With Mission Priority]:	

No.	Question
25a	What are the best select-out tools of astronaut candidates and best select-out tools for selection of individuals to teams for specific missions to avoid possible neuropsychiatric and psychological incompatibility with the mission and fellow team members? **[ISS 1, Lunar 1, Mars 1]**
25b	What are the long-term effects of exposure to the space environment (microgravity, isolation, stress) on human neurocognitive and neurobiological functions (from cellular to behavioral levels of the nervous system)? **[ISS 2, Lunar 2, Mars 2]**
25c	What are the long-term effects of exposure to the space environment on human emotion and psychological responses, including emotional reactivity, stress responses, long-term modulation of mood and vulnerability to affective and cognitive disorders? **[ISS 3, Lunar 3, Mars 3]**
25d	What objective techniques and technologies validly and reliably identify when astronauts are experiencing distress that compromises their performance capability in space? **[ISS 1, Lunar 1, Mars 1]**
25e	What are the best behavioral, technological and pharmacological countermeasures for managing cognitive dysfunction, neuropsychiatric and behavior problems in space? **[ISS 3, Lunar 3, Mars 3]**
25f	What are the best behavioral, psychological, technological and pharmacological countermeasures for managing emotional and stress-related problems in space? **[ISS 3, Lunar 3, Mars 3]**
25g	What are the best techniques and technologies for identification and treatment of cognitive disorders, neuropsychiatric and behavior problems in space? **[ISS 4, Lunar 4, Mars 4]**
25h	What are the strategies for psychological stress management, and maintaining the morale and acceptable functioning and safety of remaining crewmembers after an adverse event during a mission? **[ISS 3, Lunar 1, Mars 1]**

Related Risks :

Sensory-Motor Adaptation
Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing
Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation
Motion Sickness
Clinical Capabilities
Monitoring and Prevention
Major Illness and Trauma
Pharmacology of Space Medicine Delivery
Ambulatory Care
Rehabilitation on Mars
Behavioral Health & Performance and Space Human Factors (Cognitive)
Human Performance Failure Due to Poor Psychosocial Adaptation
Mismatch between Crew Cognitive Capabilities and Task Demands
Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems
Radiation
Acute and Late CNS Risks
Acute Radiation Risks
Advanced Food Technology
Maintain Food Quantity and Quality
Space Human Factors Engineering

	Poorly Integrated Ground, Crew, and Automation Functions
Important References :	Ellis SR. Collision in space. Ergonomics in Design. 8;4-9, 2000. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12162316 Kanas N. Psychiatric issues affecting long-duration space missions. Aviation Space & Environmental Medicine. 69:1211-1216, 1998. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=9856550 Simpson S. Staying sane in space. Scientific American. 282:61-62, 2000. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=10736838 Burrough, B. Dragonfly: NASA and the crisis aboard Mir. NY, Harper Collins, 1998. Kanas N, Manzy D. Space Psychology and Psychiatry. El Segundo, CA, Microcosm Press, 2003. Linenger JM. Off the Planet. NY, McGraw Hill, 2000. Newkirk D. Almanac of Soviet Manned Space flight, Houston, TX, Gulf Publishing, 1990

Risk Title: Mismatch between Crew Cognitive Capabilities and Task Demands

Crosscutting Area :	Behavioral Health and Performance (BHP)
Discipline :	Behavioral Health & Performance and Space Human Factors (Cognitive)
Risk Number :	26
Risk Description :	Human performance failure may occur due to inadequate design of tools, interfaces, tasks, and information support systems. Task saturation may also occur due to compromises in crew health, human factors, and cognitive capabilities.
Context / Risk Factors :	The remote nature of space flight increases the likelihood and severity of consequences of error due to task saturation, losing skills and knowledge, or failing to find information and training materials in databases. Particularly on Moon and Mars missions, the distance and communication lags may require an autonomous response to any malfunction that may increase the incidence of performance error. This risk may be influenced by communication blackouts and lags, mission duration, required levels of autonomy, time since training, time since last performing a task, or level of support available from mission control on Earth.
Justification / Rationale :	Crews require refresher training and information support systems for numerous tasks during 6-month ISS missions (Evidence Level 4). Psychological literature documents increases in error with time since learning, and decreases in error with correctly practicing the task (Evidence level 1). Failure to correctly follow procedures has led to fatal accidents in commercial aviation, even with greatly over-learned tasks (NTSB Reports-Level 2)
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Crew resilience is the countermeasure for schedule and interface problems • Mission Control provides training, information, and procedures as required to support crew actions and decision-making • Efforts by mission planners to maintain realistic workloads and schedules
Projected Countermeasures or Mitigations & other Deliverables:	• Design requirements for communications systems among crewmembers, between crew and mission control, and among crew and intelligent agents, that reduce risk of mission failure [TRL 2] • Onboard training systems that enable successful readiness to perform [TRL 2]

	• Tools for analyzing tasks to identify critical skills and knowledge [TRL 2] • Tools for enabling crew autonomy with respect to information retrieval [TRL 2] • Tools to enable self-assessment of readiness to perform [TRL 2]
Research & Technology Questions [With Mission Priority]:	(see table below)

No.	Question
26a	What crew size and composition is required to provide the amount of information, variety of skills, etc. required to accomplish the reference mission? **[ISS 2, Lunar 1, Mars 1]**
26b	What is required to counteract the negative effects of communications lags on human performance? **[ISS 1, Lunar 1, Mars 1]**
26c	What information systems, interface designs, intelligent systems and other tools to enable autonomy are required to enable human performance to be maintained at an acceptable level over the reference missions? (Shared - Integrated Testing supports) **[ISS 2, Lunar 1, Mars 1]**
26d	What types and techniques of training are required and within what timeframes, to enable the crewmembers to accomplish the mission with increased effectiveness, efficiency and safety? **[ISS 1, Lunar 1, Mars 1]**
26e	What principles of task design, procedures, job aids and tools and equipment, are required to enable crewmembers to accomplish nominal and emergency perceptual and cognitive tasks? **[ISS 2, Lunar 1, Mars 1]**
26f	How can crewmembers and ground support personnel detect and compensate for decreased cognitive readiness to perform? **[ISS 1, Lunar 1, Mars 1]**
26g	What scheduling constraints are required to reduce the risk of human error due to fatigue? (shared with Sleep and Circadian Rhythm) **[ISS 2, Lunar 2, Mars 2]**
26h	What tools and techniques will maintain the crew's situational awareness at a level sufficient to perform nominal and emergency tasks? **[ISS 2, Lunar 1, Mars 1]**
26i	What characteristics of equipment, tool and computer displays; instructions, procedures, labels and warning; and human-computer interaction designs will maintain critical sensory and cognitive capabilities? **[ISS 2, Lunar 2, Mars 2]**
26j	What approaches to human computer interactions will maintain crew critical capabilities to assess, control and communicate? **[ISS 2, Lunar 2, Mars 2]**
26k	What decision-support systems are required to aid crew decision-making? **[ISS 2, Lunar 2, Mars 2]**
26l	What design considerations are needed to accommodate effects of changes in gravity on perception (Launch, lunar landing, lunar launch, Earth return)? **[ISS N/A, Lunar 1, Mars 1]**

Related Risks :

Sensory-Motor Adaptation
Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing
Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation
Clinical Capabilities
Medical Informatics, Technologies, and Support Systems
Medical Skill Training and Maintenance
Behavioral Health & Performance and Space Human Factors (Cognitive)
Human Performance Failure Due to Poor Psychosocial Adaptation
Human Performance Failure Due to Neurobehavioral Problems
Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems
Space Human Factors Engineering

	Mismatch Between Crew Physical Capabilities and Task Demands Poorly Integrated Ground, Crew, and Automation Functions
Important References :	Ellis SR. Collision in space. Ergonomics in Design. 8(1): 4-9, 2000. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12162316 Human Space flight: Mission Analysis and Design, eds. W.J. Larson, L.K. Pranke. McGraw Hill Space Technology Series. 1999. Sleep, performance, circadian rhythms and light-dark cycles during two space Shuttle flights. Dijk DJ, Neri DF, Wyatt JK, Ronda JM, Riel E, Ritz-De Cecco A, Hughes RJ, Elliott AR, Prisk GK, West JB, Czeisler CA. Am J Physiol Regul Integr Comp Physiol. 2001 Nov; 281(5):R1647-64. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11641138 Handbook of Human Factors and Ergonomics (2nd ed), G. Salvendy, ed. John Wiley and Sons, Inc. 1997. Handbook of Human Factors Testing and Evaluation, 2nd ed. S. G. Charlton, T.G. O?Brien, eds. 2002. Woolford B, Hudy CE, Whitmore M, Berman A, Maida J, and Pandya A. (2002) In Situ Training Project: LMLSTP Phase III Report. In Lane, H.W., Sauer, R.L. and Feeback, D.L. (Eds.), ISOLATION: NASA Experiments in Closed Environment Living. Advanced Human Life Support Enclosed System Final Report. San Diego, CA: American Astronautical Society.

Risk Title: Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems

Crosscutting Area :	Behavioral Health and Performance (BHP)
Discipline :	Behavioral Health & Performance and Space Human Factors (Cognitive)
Risk Number :	27
Risk Description :	Human performance failure may occur due to circadian disruption, and acute or chronic degradation of sleep quality and quantity.
Context / Risk Factors :	Circadian disruption, or acute or chronic degradation of sleep quality or quantity, is a known risk during space flight. This risk may be influenced by artificial and transmitted ambient light exposure, individual differences in vulnerability to sleep loss and circadian dynamics, or work shift and sleep schedules.
Justification / Rationale :	Loss of circadian entrainment to Earth-based light-dark cycles, and chronic reduction of sleep duration in space, result in fatigue and jeopardize astronaut performance. Fatigue is a common symptom in prolonged space flight. Every study of sleep in space, including those on US, Russian, and European astronauts, has found that daily sleep is reduced to an average of 6 hours. It is reduced even more when critical operations occur, such as nighttime Shuttle dockings on ISS, or during an emergency (e.g., equipment failure). Astronaut sleep in space is also physiologically altered. Additionally, the most frequent medications taken in-flight by astronauts are hypnotics for sleep disturbances. Extensive ground-based scientific evidence documents that circadian disruptions and restriction of sleep at levels commonly experienced by astronauts can severely diminish cognitive performance capability, posing risks to individual astronaut safety and mission success.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 3 **Mars:** Priority 2
Current Countermeasures :	• Bright light entrainment prior to launch • Individual active noise cancellation at sleep • Medications • Scheduling constraints, as documented in Ground Rules & Constraints document SSP 50261-2, to protect sleep schedule and duration, and reduce crew fatigue

	• Self report monitoring during mission with personal physician conference
Projected Countermeasures or Mitigations & other Deliverables:	• Ability to monitor sleep, circadian and lighting parameters unobtrusively in order to predict physiological and behavioral responses [CRL 7] • Develop flight rule limits on critical operations during sleep period [CRL 4] • Model of performance deficit based on sleep and circadian data [CRL 6] • Personal lighting device (e.g., light visor) [CRL 6] • Sleep/circadian rhythm non-photic adjustment tools pre- in- and post-flight [CRL 5] • Sleep/circadian rhythm pharmacological interventions pre- in- and post-flight. [CRL 5] • Sleep/circadian rhythm photic adjustment tools pre- in- and post-flight [CRL 7]

Research & Technology Questions [With Mission Priority]:

No.	Question
27a	What are the acute and long-term effects of exposure to the space environment on biological rhythmicity, sleep architecture (quantity and quality), and their relationship to performance capability? **[ISS 1, Lunar 1, Mars 1]**
27b	Which countermeasures or combination of behavioral and physiological countermeasures will optimally mitigate specific performance problems associated with sleep loss and circadian disturbances during the reference missions? **[ISS 1, Lunar 1, Mars 1]**
27c	What are the long-term effects of countermeasures employed to mitigate pre, - in- and post-flight performance problems with sleep loss and circadian disturbances? **[ISS 3, Lunar 4, Mars 2]**
27d	What are the best methods for in-flight monitoring of the status of sleep, circadian functioning and light exposures for assessing the effects of sleep loss and circadian dysrhythmia on performance capability that are also portable and non-intrusive in the space flight environment? (e.g., actigraphy) **[ISS 2, Lunar 2, Mars 2]**
27e	What work, workload, and sleep schedule(s) will best enhance crew performance and mitigate adverse effects of the space environment? **[ISS 1, Lunar 1, Mars 1]**
27f	What individual biological and behavioral characteristics will best predict successful adaptation to long-term space flight of sleep, circadian physiology and the neurobehavioral performance functions they regulate? **[ISS 4, Lunar 5, Mars 1]**
27g	What mathematical and computational models should be used to predict performance associated with sleep-wake, schedule, work history, light exposure and circadian rhythm status and also provide guidelines for successful countermeasure strategies? **[ISS 1, Lunar 1, Mars 1]**

Related Risks :

Clinical Capabilities
Pharmacology of Space Medicine Delivery
Ambulatory Care
Behavioral Health & Performance and Space Human Factors (Cognitive)
Human Performance Failure Due to Poor Psychosocial Adaptation
Human Performance Failure Due to Neurobehavioral Problems
Mismatch between Crew Cognitive Capabilities and Task Demands
Radiation
Acute and Late CNS Risks
Acute Radiation Risks
Space Human Factors Engineering
Mismatch Between Crew Physical Capabilities and Task Demands

	Poorly Integrated Ground, Crew, and Automation Functions
Important References :	Akerstedt T. Work hours, sleepiness and the underlying mechanisms. J Sleep Res. 4: 15-22, 1995. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=10607206
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	Czeisler CA, AJ Chiasera and JF Duffy. Research on sleep, circadian rhythms and aging: applications to manned space flight. Exp Gerontol. 26: 217-232, 1991. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=1915692
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	Elliott AR, SA Shea, DJ Dijk, JK Wyatt, E Riel, DF Neri, CA Czeisler, JB West and GK Prisk. Microgravity reduces sleep-disordered breathing in humans. Am J Respir Crit Care Med. 164: 478-85, 2001. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11500354
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Risk Title: Carcinogenesis

Crosscutting Area :	Radiation Health (RH)
Discipline :	Radiation

<table>
<tr><td>Risk Number :</td><td>28</td></tr>
<tr><td>Risk Description :</td><td>Increased cancer morbidity or mortality risk in astronauts may be caused by occupational radiation exposure.</td></tr>
<tr><td>Context / Risk Factors :</td><td>This risk may be influenced by other space flight factors including microgravity and environmental contaminants. A Mars mission will not be feasible unless improved shielding is developed.</td></tr>
<tr><td>Justification / Rationale :</td><td>Exposure to space radiation increases the risk of developing cancer later in life.</td></tr>
<tr><td>Risk Rating :</td><td>ISS: Priority 2
Lunar: Priority 1
Mars: Priority 1</td></tr>
<tr><td>Current Countermeasures :</td><td>Polyethylene shielding
Mission design (altitude, vehicle attitude, timing of EVAÆs)
Real-time monitoring
Administrative radiation exposure limits (ALARA)</td></tr>
<tr><td>Projected Countermeasures or Mitigations & other Deliverables:</td><td>Anti-oxidants [CRL 1]
Gene therapy [CRL 1]
Pharmaceuticals [CRL 1]
Improved shielding and vehicle design to minimize radiation exposure [TRL 5]</td></tr>
<tr><td>Research & Technology Questions [With Mission Priority]:</td><td>
<table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td>28a</td><td>What are the probabilities for increased carcinogenesis from space radiation as a function of NASA's operational parameters (age at exposure, age, latency, gender, tissue, mission, radiation quality, dose rate and exposure protraction)? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>28b</td><td>How can tissue specific probabilities for increased carcinogenesis risk from space radiation be best evaluated? What molecular, genetic, epigenetic, abscopal (effect that irradiation of a tissue has on remote non-irradiated tissue), and other factors contribute to the tissue specificity of carcinogenic risk? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>28c</td><td>How can the individual's sensitivity to radiation carcinogenesis be estimated? [ISS 2, Lunar 2, Mars 1]</td></tr>
<tr><td>28d</td><td>How can effective biomarkers of carcinogenic risk from space radiation be developed and validated? [ISS 3, Lunar 3, Mars 2]</td></tr>
<tr><td>28e</td><td>What are the most effective biomedical or dietary countermeasures to mitigate cancer risks? By what mechanisms are the countermeasures expected to work, and do they have the same efficiency for low- and high-LET radiation? [ISS 3, Lunar 3, Mars 1]</td></tr>
<tr><td>28f</td><td>How can animal models (including genetic models such as those developed by gene targeting or the use of other transgenic approaches) of carcinogenesis be developed to improve estimates of cancers from space radiation and what longitudinal studies are needed? [ISS 2, Lunar 2, Mars 1]</td></tr>
<tr><td>28g</td><td>What improvements can be made to quantitative procedures or theoretical models in order to extrapolate molecular, cellular, or animal results to determine the risks of specific cancers in astronauts? How can human epidemiology data best support these procedures or models? [ISS 3, Lunar 3, Mars 2]</td></tr>
<tr><td>28h</td><td>Are there significant combined effects from other space flight factors (microgravity, stress, altered circadian rhythms, changes in immune responses, viral reactivation etc.) that modify the carcinogenic risk from space radiation? [ISS 5, Lunar 5, Mars 3]</td></tr>
<tr><td>28i</td><td>What are the probabilities that space radiation will produce DNA damage at specific sites, including clustered DNA damage? What is the likelihood that DNA damage will increase the risk of carcinogenesis? [ISS 3, Lunar 3, Mars 2]</td></tr>
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	28j — What mechanisms modulate radiation damage at the molecular level (e.g., repair, errors in repair, signal transduction, gene amplification, bystander effects, tissue microenvironment, etc.) that significantly impact the risk of cancers, modulate the expression of radiation damage and decrease the radiation risk, and how can the understanding of mechanisms be used to predict carcinogenic risks from space radiation? **[ISS 2, Lunar 2, Mars 1]** 28k — What space validation experiments could improve estimates of carcinogenic risks for long-term deep-space missions? **[ISS 5, Lunar 5, Mars 3]** 28l — What are the most effective shielding approaches to mitigate cancer risks? **[ISS 1, Lunar 1, Mars 1]** 28m — What new materials or active shielding methods can be used for reducing space radiation cancer risks? **[ISS 1, Lunar 1, Mars 1]** 28n — What are the most effective approaches to integrate radiation shielding analysis codes with collaborative engineering design environments used by spacecraft and planetary habitat design efforts? **[ISS 4, Lunar 1, Mars 1]** 28o — What is the most effective approach to use data from robotic Mars probes on the atmospheric, soil, and magnetic properties of the red planet for estimating carcinogenesis risk, and designing effective shielding or biological countermeasures? **[ISS 5, Lunar 5, Mars 2]** 28p — What are the critical nuclear interaction experimental data and predictive theoretical models needed to complete radiation shielding analysis codes in support of exploration spacecraft and planetary habitat designs? **[ISS 5, Lunar 2, Mars 1]**
Related Risks :	**Immunology & Infection** Immune Dysfunction, Allergies and Autoimmunity Interaction of Space flight Factors, Infections and Malignancy **Nutrition** Inadequate Nutrition **Clinical Capabilities** Pharmacology of Space Medicine Delivery **Behavioral Health & Performance and Space Human Factors (Cognitive)** Human Performance Failure Due to Poor Psychosocial Adaptation Human Performance Failure Due to Neurobehavioral Problems Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems **Radiation** Acute and Late CNS Risks Chronic and Degenerative Tissue Risks Acute Radiation Risks **Advanced Environmental Monitoring & Control** Monitor External Environment
Important References :	Alpen EL, Powers-Risius P, Curtis SB and DeGuzman R. Tumorigenic potential of high-Z, high-LET charged-particle radiations. Radiation Research. 136: 382-391, 1993. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=8278580 Berrington A, et al. 100 Years of observation of British radiologists: mortality from cancer and other causes 1897-1997. Br J Radio 74: 507-519, 2001. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12595318

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Risk Title: Acute and Late CNS Risks

Crosscutting Area :	Radiation Health (RH)
Discipline :	Radiation
Risk Number :	29
Risk Description :	Acute and late radiation damage to the central nervous system (CNS) may lead to changes in motor function and behavior, or neurological disorders. This may be caused by occupational radiation exposure or the combined effects of radiation and other space flight factors.
Context / Risk Factors :	Radiation (space, medical diagnostic, atmospheric, experimental and nuclear sources including propulsion systems) and synergistic effects of radiation with other space flight factors may affect neural tissues, which in turn may lead to changes in function or behavior.
Justification / Rationale :	Crew health and performance in-flight may be affected.This risk will be most significant during a Mars mission, with a long travel time and no return capability.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 2

	Mars: Priority 1
Current Countermeasures :	• Polyethylene shielding • Avoidance of the South Atlantic Anomaly (SAA) • ALARA, and monitoring of exposure limits • Vehicle altitude and attitude changes
Projected Countermeasures or Mitigations & other Deliverables:	• Anti-oxidants [CRL 1] • Hydrogenous shielding [TRL 5] • Pharmaceuticals [CRL 1] • Autonomous monitoring [Lunar] [Mars] • Improved shielding materials [Lunar] [Mars] • Pharmacological cellular protectants will be required [Lunar] [Mars]

Research & Technology Questions [With Mission Priority]:

No.	Question
29a	Is there a significant probability that space radiation would lead to immediate or acute functional changes in the CNS due to a long-term space mission and if so what are the mechanisms of change? **[ISS 3, Lunar 3, Mars 1]**
29b	Is there a significant probability that space radiation exposures would lead to long-term or late degenerative CNS risks? If so what are the mechanisms of change? **[ISS 3, Lunar 3, Mars 1]**
29c	How does individual susceptibility including hereditary pre-disposition (Alzheimer's, Parkinson's, apoE) and prior CNS injury (concussion or other) alter significant CNS risks? **[ISS 3, Lunar 3, Mars 1]**
29d	What are the most effective biomedical or dietary countermeasures to mitigate CNS risks? By what mechanisms do the countermeasures work? **[ISS 4, Lunar 4, Mars 1]**
29e	How can animal models of CNS risks, including altered motor and cognitive function, behavioral changes and late degenerative risks be best used for estimating space radiation risks to astronauts? **[ISS 4, Lunar 3, Mars 1]**
29f	Are there significant CNS risks from combined space radiation and other physiological or space flight factors (e.g., bone loss, microgravity, immune-endocrine systems or other)? **[ISS 5, Lunar 5, Mars 3]**
29g	What are the molecular, cellular and tissue mechanisms of damage [DNA damage processing, oxidative damage, cell loss through apoptosis or necrosis, changes in the extra-cellular matrix, cytokine activation, inflammation, changes in plasticity, micro-lesion (clusters of damaged cells along heavy ion track) etc.] in the CNS? **[ISS 4, Lunar 3, Mars 1]**
29h	What are the different roles of neural cell populations, including neuronal stem cells and their integrative mechanisms in the morphological and functional consequences of space radiation exposure? **[ISS 2, Lunar 2, Mars 1]**
29i	Are there biomarkers for detecting damage or susceptibility to/for radiation-induced CNS damage? **[ISS 4, Lunar 3, Mars 2]**
29j	What quantitative procedures or theoretical models are needed to extrapolate molecular, cellular, or animal results to predict CNS risks in astronauts? How can human epidemiology data best support these procedures or models? **[ISS 4, Lunar 3, Mars 2]**
29k	What are the most effective shielding approaches to mitigate CNS risks? **[ISS 1, Lunar 1, Mars 1]**
29l	What space validation experiments could improve estimates of CNS risks for long-term deep-space missions? **[ISS 5, Lunar 5, Mars 3]**

Related Risks : **Bone Loss**

	Accelerated Bone Loss and Fracture Risk **Cardiovascular Alterations** Occurrence of Serious Cardiac Dysrhythmias **Immunology & Infection** Immune Dysfunction, Allergies and Autoimmunity Interaction of Space flight Factors, Infections and Malignancy **Sensory-Motor Adaptation** Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation **Nutrition** Inadequate Nutrition **Clinical Capabilities** Monitoring and Prevention Major Illness and Trauma Pharmacology of Space Medicine Delivery Ambulatory Care **Behavioral Health & Performance and Space Human Factors (Cognitive)** Human Performance Failure Due to Neurobehavioral Problems **Radiation** Carcinogenesis Chronic and Degenerative Tissue Risks Acute Radiation Risks
Important References :	Joseph JA, Hunt WA, Rabin BM and Dalton TK. Possible "Accelerated Striatal Aging" Induced by 56Fe Heavy Particle Irradiation: Implications for Manned Space flights. Radiat Res. 130: 88-93, 1992. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=1561322 Lett JT and Williams GR. Effects Of LET On The Formation And Fate Of Radiation Damage To Photoreceptor Cell Component Of The Rabbit Retina: Implications For The Projected Manned Mission To Mars. In Biological Effects Of Solar And Galactic Cosmic Radiation, Part A (C.E. Swenberg, G. Horneck and e.g., Stassinopoulos, Eds.) 185-201, Plenum Press, NY, NY: 1993. National Academy of Sciences Space Science Board, HZE Particle Effects in Manned Space flight, National Academy of Sciences U.S.A. Washington D.C., 1973. National Academy of Sciences, NAS. National Academy of Sciences Space Science Board, Report of the Task Group on the Biological Effects of Space Radiation. Radiation Hazards to Crews on Interplanetary Mission National Academy of Sciences, Washington, D.C., 1997. Rabin BM, Joseph JA, Shukitt-Hale B. and McEwen J. Effects of Exposure to Heavy Particles on a Behavior Medicated by the Dopaminergic System. Adv. Space Res. 25, (10) 2065-2074, 2000. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11542858 Surma-aho O, et al. Adverse Long-Term Effects of Brain Radiotherapy in Adult Low-Grade Glioma Patients. Neurology. 56: 1285-1290, 2001. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11376174

	Todd P. Stochastics of HZE-Induced Microlesions. Adv in Space Res. 9(10): 31-34, 1981. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11537310 Tolifon PJ and Fike JR. The radioresponse of the Central Nervous System: A Dynamic Process. Radiat Res. 153: 357-370, 2000. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=10798963

Risk Title: Chronic and Degenerative Tissue Risks

Crosscutting Area :	Radiation Health (RH)
Discipline :	Radiation
Risk Number :	30
Risk Description :	Radiation exposure may result in degenerative tissue diseases (non-cancer or non-CNS) such as cardiac, circulatory, or digestive diseases, as well as cataracts. This may be caused by occupational radiation exposure or the combined effects of radiation and other space flight factors.
Context / Risk Factors :	Radiation (space, medical diagnostic, atmospheric, experimental and nuclear sources including propulsion systems) and synergistic effects of radiation cause increased DNS strand and tissue degeneration, which may lead to acute or chronic disease of susceptible organ tissues. The risk may also be influenced by microgravity or physiological changes.
Justification / Rationale :	Acute or chronic illness due to tissue degeneration may lead to mission impacts, or adverse health consequences after return.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Polyethylene shielding • Avoidance of the South Atlantic Anomaly (SAA) • ALARA, and monitoring of exposure limits • Vehicle altitude and attitude changes
Projected Countermeasures or Mitigations & other Deliverables:	• Anti-oxidants [CRL 1] • Hydrogenous shielding [TRL 5] • Pharmaceuticals [CRL 1] • Autonomous monitoring [Lunar] [Mars] • Improved shielding materials [Lunar] [Mars] • Pharmacological cellular protectants [Lunar] [Mars]
Research & Technology Questions [With Mission Priority]:	

No.	Question
30a	What are the probabilities for degenerative tissue risks from protons and HZE ions as a function of NASA's operational parameters (age at exposure, age and time after exposure, gender, tissue, mission, radiation quality, dose rate)? **[ISS 2, Lunar 2, Mars 1]**
30b	What are the mechanisms of degenerative tissues risks in the heart, circulatory, endocrine, digestive, lens and other tissue systems? **[ISS 2, Lunar 2, Mars 1]**
30c	How can the latency period for degenerative tissue risks, including sub-clinical diseases, following space radiation exposures be estimated? **[ISS 3, Lunar 3, Mars 1]**

	30d	What are the most effective biomedical or dietary countermeasures to degenerative tissue risks? By what mechanisms do the countermeasures work? **[ISS 3, Lunar 3, Mars 1]**
	30e	What quantitative procedures or theoretical models are needed to extrapolate molecular, cellular, or animal results to predict degenerative tissue risks in astronauts? How can human epidemiology data best support these procedures or models? **[ISS 4, Lunar 4, Mars 2]**
Related Risks :		**Cardiovascular Alterations**
		Occurrence of Serious Cardiac Dysrhythmias
		Immunology & Infection
		Immune Dysfunction, Allergies and Autoimmunity
		Interaction of Space flight Factors, Infections and Malignancy
		Skeletal Muscle Alterations
		Increased Susceptibility to Muscle Damage
		Nutrition
		Inadequate Nutrition
		Clinical Capabilities
		Monitoring and Prevention
		Pharmacology of Space Medicine Delivery
		Radiation
		Carcinogenesis
		Acute and Late CNS Risks
		Acute Radiation Risks
Important References :		Berrington A., et al. 100 Years of observation of British radiologists: mortality from cancer and other causes 1897-1997. Br J Radio. 74:507-519, 2001. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12595318
		Boivin JF, et al. Coronary Artery Disease Mortality in Patients Treated for Hodgkins Disease. Cancer. 69: 1241-1247, 1992. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=1739922
		Cucinotta FA, Manuel F, Jones,J, Izsard G, Murray J, Djojonegoro B. and Wear M. Space Radiation and Cataracts in Astronauts. Radiation Research. 156: 460-466, 2001. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11604058
		Hauptmann M, et. al. Mortality from Diseases of the Circulatory System in Radiologic Technologists in the United States. American Journal of Epidemiology. 157: 239-248, 2003. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12543624
		National Academy of Sciences Space Science Board, Report of the Task Group on the Biological Effects of Space Radiation. Radiation Hazards to Crews on Interplanetary Mission National Academy of Sciences, Washington, D.C., 1997.
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	Otake M, Neriishi K and Schull WJ. Cataract in atomic bomb survivors based on a threshold and the occurrence of severe epilation. Radiation Research. 146: 339-348, 1996. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=8752314
	Preston DL, et al. Studies of mortality of atomic bomb survivors Report 13: Solid cancer and noncancer disease mortality: 1950-1997. Radiation Research. 160, 381-407, 2003. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12968934
	Schimizu Y, et al. Studies of the Mortality of Atomic Bomb Survivors. Report 12, Part II: Non-cancer mortality: 1950-1990. Radiation Research. 152: 374-389, 1999. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=10477914
	Stewart JR and Faiardo LF. Radiation-induced heart disease. Clinical and experimental aspects. Radiological Clinical Journal of North America. 9: 511-531, 1971. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=5001977

Risk Title: Acute Radiation Risks

Crosscutting Area :	Radiation Health (RH)
Discipline :	Radiation
Risk Number :	31
Risk Description :	Acute radiation syndromes may occur due to occupational radiation exposure.
Context / Risk Factors :	Radiation (space, medical diagnostic, atmospheric, experimental and nuclear sources including propulsion systems) and synergistic effects of radiation may place the crew at significant risk for acute radiation sickness, such that the mission or crew survival may be placed in jeopardy.
Justification / Rationale :	Crew health and performance may be impacted by acute solar events. Beyond Low Earth Orbit, the protection of the Earth's atmosphere is no longer available, such that increased shielding and protective mechanisms are necessary in order to prevent acute radiation sickness and impacts to mission success or crew survival.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Polyethylene shielding • Avoidance of the South Atlantic Anomaly (SAA) • Vehicle altitude and attitude changes • ALARA, and monitoring of radiation exposure limits
Projected Countermeasures or Mitigations & other Deliverables:	• Anti-oxidants [CRL 1] • Hydrogenous shielding [TRL 5] • Pharmaceuticals [CRL 1] • Autonomous monitoring [Lunar] [Mars] • Improved shielding materials [Lunar] [Mars] • Pharmacological cellular protectants [Lunar] [Mars]
Research & Technology Questions [With Mission Priority]:	**No.** | **Question**

	31a	How can predictions of acute space radiation events be improved? **[ISS 5, Lunar 3, Mars 3]**
	31b	Are there synergistic effects arising from other space flight factors (microgravity, stress, immune status, bone loss, damage to intestinal cells reducing their ability to absorb medication etc.) that modify acute risks from space radiation including modifying thresholds for such effects? **[ISS 4, Lunar 3, Mars 3]**
	31c	What are the molecular, cellular and tissue mechanisms of acute radiation damage (DNA damage processing, oxidative damage, cell loss through apoptosis or necrosis, cytokine activation, etc.)? **[ISS 4, Lunar 3, Mars 3]**
	31d	Does protracted exposure to space radiation modify acute doses from SPEs in relationship to acute radiation syndromes? **[ISS 4, Lunar 3, Mars 3]**
	31e	What are the most effective biomedical or dietary countermeasures to mitigate acute radiation risks? By what mechanisms do the countermeasures work? **[ISS 4, Lunar 3, Mars 3]**
	31f	What quantitative procedures or theoretical models are needed to extrapolate molecular, cellular, or animal results to predict acute radiation risks in astronauts? How can human epidemiology data best support these procedures or models? **[ISS 4, Lunar 3, Mars 3]**
	31g	What are the most effective shielding approaches to mitigate acute radiation risks? **[ISS 1, Lunar 1, Mars 1]**
	31h	What are the most effective "storm shelter" shielding approaches to protect against large solar particle events in deep space or on planetary surfaces? **[ISS 3, Lunar 1, Mars 1]**

Related Risks :	**Bone Loss**
	Accelerated Bone Loss and Fracture Risk
	Cardiovascular Alterations
	Occurrence of Serious Cardiac Dysrhythmias
	Immunology & Infection
	Immune Dysfunction, Allergies and Autoimmunity
	Interaction of Space flight Factors, Infections and Malignancy
	Nutrition
	Inadequate Nutrition
	Clinical Capabilities
	Monitoring and Prevention
	Major Illness and Trauma
	Pharmacology of Space Medicine Delivery
	Behavioral Health & Performance and Space Human Factors (Cognitive)
	Human Performance Failure Due to Neurobehavioral Problems
	Radiation
	Carcinogenesis
	Acute and Late CNS Risks
	Chronic and Degenerative Tissue Risks
	Advanced Environmental Monitoring & Control
	Monitor External Environment

Important References :	Ainsworth EJ. Early and late mammalian responses to heavy charged particles. Advances in Space Research. 6: 153-165, 1986. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11537215 National Council on Radiation Protection and Measurements, NCRP. Guidance on Radiation Received in Space Activities, NCRP Report 98, NCRP, Bethesda (MD), 1989. National Council on Radiation Protection and Measurements, Recommendations of Dose Limits for Low Earth Orbit. NCRP Report 132, Bethesda MD, 2000. Todd P, Pecautt MJ, Fleshner M. Combined effects of space flight factors and radiation on humans. Mutation Res. 430: 211-219, 1999. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=10631335

Risk Title: Monitor Air Quality

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Environmental Monitoring & Control
Risk Number :	32
Risk Description :	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 by automated response equipment, leading to increased hazards to the crew.
Context / Risk Factors :	Chemical and microbial detection in the crew atmosphere, or elsewhere in the air processing system, can indicate the buildup of microbial contaminants, hazardous chemicals, pre-combustion reaction products, malfunction of life support equipment, or other hazardous events such as accidental release from an experiment. This risk may be influenced by accidental events such as fire or leak, or a malfunction in the life support system, which may be gradual or sudden.
Justification / Rationale :	Technologies must be able to detect both anticipated and unanticipated events and identify the problem source. Gradual buildup of toxic chemicals may take months, calling for highly sensitive detection at slow intervals, perhaps daily. Leakage or pre-combustion events are expected to occur more rapidly, requiring more rapid detection (minutes), though less sensitive detection may be necessary. Existing technology is critical resource intensive and requires substantial improvement in efficiency, reliability, and functionality. For example, no single technology currently can address all Spacecraft Maximum Allowable Concentration (SMAC) chemicals, combustion in micro, lunar and Martian gravity is very different from combustion on Earth and has different pre-combustion indicators, and harmful foreign matter may be inadvertently brought in following extravehicular activity (EVA). The same monitoring technology may be useful for helping diagnose crew health by providing breath-monitoring data.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 1 **Mars:** Priority 1
Current Countermeasures :	• ISS Compound Specific Combustion Product Analyzer • Crew indicators such as reports of odor, nausea • Ground analysis of returned samples • ISS Major Constituent Analyzer • ISS Volatile Organic Analyzer • Materials selection • Scheduled maintenance and housekeeping
Projected Countermeasures or Mitigations & other Deliverables:	• Distributed network of rapid, smaller detectors [TRL 4] • Highly sensitive somewhat slower analyzer suite [TRL 4]

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<tr><td>Research & Technology Questions [With Mission Priority]:</td><td>
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<tr><th>No.</th><th>Question</th></tr>
<tr><td>32a</td><td>What technologies can be used to detect slow, gradual changes in the chemical and microbial environment ?(work with Environmental Health) [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>32b</td><td>What set of technologies and data can be used to quickly diagnose potentially hazardous events from chemical data? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>32c</td><td>How can environmental information be used to assist in-flight biomonitoring for health and performance of the astronauts (supporting Biomedical monitoring)? [ISS 3, Lunar 3, Mars 3]</td></tr>
<tr><td>32d</td><td>What technologies must be developed to rapidly detect and address fire in space? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>32e</td><td>How can technology help ensure that appropriate responses to hazardous events are achieved in a timely manner? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>32f</td><td>What set of technologies and data can be used to detect and diagnose hardware malfunction, in such systems as life support or in situ resource utilization by assessment of environmental (air, water, or surfaces) changes? (work with ALS) [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>32g</td><td>What technologies can detect both anticipated and unanticipated species and events? [ISS 1, Lunar 1, Mars 1]</td></tr>
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<tr><td>Related Risks :</td><td>
<table>
<tr><td>Environmental Health</td></tr>
<tr><td>Define Acceptable Limits for Contaminants in Air and Water</td></tr>
<tr><td>Clinical Capabilities</td></tr>
<tr><td>Monitoring and Prevention</td></tr>
<tr><td>Advanced Environmental Monitoring & Control</td></tr>
<tr><td>Monitor External Environment</td></tr>
<tr><td>Provide Integrated Autonomous Control of Life Support Systems</td></tr>
<tr><td>Advanced Life Support</td></tr>
<tr><td>Maintain Acceptable Atmosphere</td></tr>
<tr><td>Maintain Thermal Balance in Habitable Areas</td></tr>
<tr><td>Provide and Maintain Bioregenerative Life Support Systems</td></tr>
<tr><td>Space Human Factors Engineering</td></tr>
<tr><td>Mismatch Between Crew Physical Capabilities and Task Demands</td></tr>
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<tr><td>Important References :</td><td>
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<tr><td>"Cabin Air Quality Dynamics on Board the International Space Station" J Perry, B Peterson, 33rd International Conference on Environmental Systems, SAE#2003-01-2650, July 2003.</td></tr>
<tr><td>"Toxicological Assessment of the International Space Station Atmosphere with Emphasis on Metox Canister Regeneration" J James, 33rd International Conference on Environmental Systems, SAE#2003-01-2647, July 2003.</td></tr>
<tr><td>Advanced Technology for Human Support in Space, National Research Council Report, 1997. Downloadable from http://peer1.nasaprs.com/peer_review/prog/nap.pdf

http://peer1.nasaprs.com/peer_review/prog/nap.pdf</td></tr>
<tr><td>NASA/JSC Toxicology Group Home Page http://www.jsc.nasa.gov/toxicology/

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Risk Title: Monitor External Environment

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Environmental Monitoring & Control

Risk Number :	33
Risk Description :	Failure to detect hazards external to the habitat (e.g., dust, fuel contaminants) can lead to lack of remedial action, and poses an increased risk to the crew.
Context / Risk Factors :	Potentially harmful substances may exist external to the habitat. They may be generated by the spacecraft, such as fuel or hydraulic residue, or they may be native to the environment, such as erosive or chemically reactive dust.
Justification / Rationale :	Possible events include leakage of ammonia coolant, of cabin atmosphere, or of rocket propellant. The lunar or Martian environment itself may have some hazard such as the chemical composition or physical nature of the dust. It is expected that in some cases these can be readily detected during extravehicular activity (EVA).
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 1 **Mars:** Priority 1
Current Countermeasures :	• ISS Trace Gas Analyzer (TGA) using miniature quadrupole mass spectrometry technology • Procedures for decontamination and monitoring and cleanup following chemical exposure while EVA
Projected Countermeasures or Mitigations & other Deliverables:	• Real-time radiation monitor [TRL 4] • Second generation TGA [TRL 6]
Research & Technology Questions [With Mission Priority]:	**No.** / **Question** 33a: What sensors are required to monitor hazardous conditions in the extra-vehicular environment? (work with AEVA) **[ISS 1, Lunar 1, Mars 1]**
Related Risks :	**Environmental Health** Define Acceptable Limits for Contaminants in Air and Water **Clinical Capabilities** Monitoring and Prevention **Radiation** Carcinogenesis Acute Radiation Risks **Advanced Environmental Monitoring & Control** Monitor Air Quality **Advanced Extravehicular Activity** Provide Space Suits and Portable Life Support Systems
Important References :	"Trace Gas Analyzer for Extra-Vehicular Activity" T Abbasi, M Christensen, M Villemarette, M Darrach, A Chutjian, 31st International Conference on Environmental Systems, SAE#2001-01-2405, July 2001.

Risk Title: Monitor Water Quality

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Environmental Monitoring & Control
Risk Number :	34
Risk Description :	Lack of timely information about the build-up of chemicals or microbial growth in the crew water supply, or elsewhere in the water reclamation system, can lead to a delayed response by the crew, or the automated response equipment, and pose a hazard to the crew.
Context / Risk	This risk may be influenced by an accidental event such as a leak of ammonia from the cooling

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<tr><td>Factors :</td><td>system into the water supply through the heat exchanger, or a malfunction in the life support system, which may be gradual or sudden.</td></tr>
<tr><td>Justification / Rationale :</td><td>Gradual buildup of toxic chemicals may take months, calling for highly sensitive detection at slow intervals, perhaps daily. Leakage events are expected to occur more rapidly, requiring more rapid detection (minutes), though less sensitive detection may be necessary. Technologies must be able to detect both anticipated and unanticipated events and phenomena. Localized information is needed to identify the problem source. Existing technology for ground-based measurement is massive, power hungry, needs hazardous reagents, requires significant crew skill and time and is sensitive to micro, lunar, or Martian gravity multiphase issues.</td></tr>
<tr><td>Risk Rating :</td><td>ISS: Priority 2
Lunar: Priority 1
Mars: Priority 1</td></tr>
<tr><td>Current Countermeasures :</td><td>Crew report of odor or taste
Ground analysis of returned samples
Manual plate culturing at ambient temperature with visual estimate
Water conductivity measurement
ISS Total Organic Carbon Analyzer</td></tr>
<tr><td>Projected Countermeasures or Mitigations & other Deliverables:</td><td>Compact online chemical water analyzer suite [TRL 3]
Microbial analysis instrument [TRL 3]</td></tr>
<tr><td>Research & Technology Questions [With Mission Priority]:</td><td><table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td>34a</td><td>What technologies can be used to detect slow, gradual changes in the chemical and microbial environment? (work with ALS and Environmental Health) [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>34b</td><td>What set of technologies and data can be used to quickly diagnose potentially hazardous events from chemical data? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>34c</td><td>How can technology help ensure that appropriate responses to hazardous events are achieved in a timely manner? (Needed for developing automated systems.) [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>34d</td><td>What set of technologies and data can be used to detect and diagnose hardware malfunction by assessment of environmental (air, water, or surfaces) changes? (work with ALS) [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>34e</td><td>What technologies can detect both anticipated and unanticipated species and events? [ISS 1, Lunar 1, Mars 1]</td></tr>
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<tr><td>Environmental Health</td></tr>
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<tr><td>Advanced Life Support</td></tr>
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<tr><td>Provide and Maintain Bioregenerative Life Support Systems</td></tr>
<tr><td>Provide and Recover Potable Water</td></tr>
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<tr><td>Important References :</td><td><table><tr><td>"ISS Potable Water Sampling and Chemical Analysis: Expeditions 4-6" D Plumlee, P Mudgett, J Schultz, J James, 33rd International Conference on Environmental Systems, SAE#2003-01-2401, July 2003.</td></tr></table></td></tr>
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	Advanced Technology for Human Support in Space, National Research Council Report, 1997. Downloadable from http://peer1.nasaprs.com/peer_review/prog/nap.pdf http://peer1.nasaprs.com/peer_review/prog/nap.pdf
	AEMC Technology Development Requirements (1998) downloadable from http://peer1.nasaprs.com/peer_review/prog/prog.html http://peer1.nasaprs.com/peer_review/prog/prog.html
	Characterization and Monitoring of Microbial Species in the International Space Station Drinking Water. M LaDuc, 33rd International Conference on Environmental Systems, SAE#2003-01-2404, July 2003.
	NASA/JSC Toxicology Group Home Page http://www.jsc.nasa.gov/toxicology/ http://www.jsc.nasa.gov/toxicology/

Risk Title: Monitor Surfaces, Food, and Soil

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Environmental Monitoring & Control
Risk Number :	35
Risk Description :	Lack of timely information, or failure to detect the presence of harmful chemicals or microbial growth on surfaces, food supplies, or soil (required for plant growth) can pose a crew health hazard.
Context / Risk Factors :	Low gravity environments allow for greater accumulation of liquids on surfaces by surface tension and longer persistence of matter suspended in air, increasing the likelihood of surface impact.
Justification / Rationale :	The area of contamination of surfaces in the space environment has received relatively little attention to date. The risk is essentially unknown.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 1 **Mars:** Priority 1
Current Countermeasures :	• Occasional manual plate culturing of samples from swabbed surfaces • Regular and as needed housecleaning
Projected Countermeasures or Mitigations & other Deliverables:	• Detection and identification of surface contamination by optical interrogation [TRL 3] • Reliable, repeatable sampling methods taking minimal crew time [TRL 2]

Research & Technology Questions [With Mission Priority]:

No.	Question
35a	What technologies can be used to detect slow, gradual changes in the chemical and microbial surface environment? (work with Environmental Health and ALS) **[ISS 1, Lunar 1, Mars 1]**
35b	What set of technologies and data can be used to quickly diagnose potentially hazardous events from chemical data? **[ISS 1, Lunar 1, Mars 1]**
35c	What technologies are required to meet the radiation monitoring requirements of a mission? **[ISS 2, Lunar 1, Mars 1]**
35d	What sample acquisition and preparation technologies can meet the requirements of the gaseous, aqueous and solid-phase matrices monitoring? **[ISS 1, Lunar 1, Mars 1]**
35e	What research is required to validate design approaches for multiphase flow for monitoring systems in varying gravity environments? **[ISS 1, Lunar 2, Mars 2]**

Related Risks :

Environmental Health
Define Acceptable Limits for Contaminants in Air and Water
Clinical Capabilities

	Monitoring and Prevention **Advanced Food Technology** Maintain Food Quantity and Quality **Advanced Life Support** Maintain Acceptable Atmosphere
Important References :	Advanced Technology for Human Support in Space, National Research Council Report, 1997. Downloadable from http://peer1.nasaprs.com/peer_review/prog/nap.pdf http://peer1.nasaprs.com/peer_review/prog/nap.pdf AEMC Technology Development Requirements (1998) downloadable from http://peer1.nasaprs.com/peer_review/prog/prog.html http://peer1.nasaprs.com/peer_review/prog/prog.html

Risk Title: Provide Integrated Autonomous Control of Life Support Systems

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Environmental Monitoring & Control
Risk Number :	36
Risk Description :	Lack of stable, reliable, efficient process control for the life support system can pose a hazard to crew health or create an excessive crew workload.
Context / Risk Factors :	Decreasing life support system mass by decreasing air or water buffer sizes (an economically desirable objective) increases the potential for the system to become unstable. Additionally, longer mission durations, such as with the Mars scenario, mean greater potential for the life support system to become unstable.
Justification / Rationale :	Automated control of life support is needed to minimize the crew workload. Industrial process control technology is manufacturing-oriented (input/output) with a narrow range of time constants. Space life support is an endless loop-recycling environment, with time constants ranging from fast accidental incidents to life cycles of plant crops (months). Advances in process control technology are needed for safe, efficient control of the life support system.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Manual and low level process control
Projected Countermeasures or Mitigations & other Deliverables:	• Automated control of life support, integrated with monitoring system [TRL 2]
Research & Technology Questions [With Mission Priority]:	

No.	Question
36a	How do we design an effective control system with flexibility, modularity, growth potential, anti-obsolescence and accommodate varied, new, & unknown test articles, taking advantage of standards? (work with Integrated Testing) **[ISS 1, Lunar 1, Mars 1]**
36b	How does a control system manage and plan for the long time constants of certain biological processes that lead to changes days, months later; and reconciles between discrete events, continuous processing and varying time constants? (work with Integrated Testing) **[ISS 1, Lunar 1, Mars 1]**
36c	How do we assure that human situation awareness is at a high level when needed, while offloading the crew workload for most of the time? (work with SHFE and Integrated Testing) **[ISS 2, Lunar 2, Mars 2]**

36d	How can a control system support strategic decisions; launch readiness/abort/return home decisions and procedures? (work with SHFE and Integrated Testing) **[ISS 1, Lunar 1, Mars 1]**
36e	How can we develop real time prognostic capabilities to predict failures before they occur and degradations before they have impact? (work with ALS and Integrated Testing) **[ISS 1, Lunar 1, Mars 1]**
36f	How do we allocate efficiently and safely between space-based control and ground-based control? (work with SHFE and Integrated Testing) **[ISS 1, Lunar 1, Mars 1]**
36g	In very large and complex systems, how can we synchronize system states across subsystems? (work with Integrated Testing) **[ISS 1, Lunar 1, Mars 1]**
36h	How do we trade between buffers and controls to ensure safe and reliable system? (work with ALS and Integrated Testing) **[ISS 1, Lunar 1, Mars 1]**
36i	How can understanding process control help determine which sensors may be missing and where sensors should be placed? (work with Integrated Testing) **[ISS 1, Lunar 1, Mars 1]**

Related Risks :

Environmental Health
Define Acceptable Limits for Contaminants in Air and Water
Advanced Environmental Monitoring & Control
Monitor Air Quality
Advanced Extravehicular Activity
Provide Space Suits and Portable Life Support Systems
Advanced Life Support
Maintain Acceptable Atmosphere
Provide and Maintain Bioregenerative Life Support Systems
Provide and Recover Potable Water
Space Human Factors Engineering
Mismatch Between Crew Physical Capabilities and Task Demands
Poorly Integrated Ground, Crew, and Automation Functions

Important References :

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AEMC Technology Development Requirements (1998) downloadable from http://peer1.nasaprs.com/peer_review/prog/prog.html http://peer1.nasaprs.com/peer_review/prog/prog.html
Final Report, Workshop on Advanced System Integration and Control for Life Support (ASICLS) Monterey Plaza Hotel , 26-28 August 2003, Monterey, CA
NASA Advanced Environmental Monitoring and Control (AEMC) Program Review, Final Report, USRA, August 1999. Also, AEMC review response sent to HQ Sept 1999.

Risk Title: Provide Space Suits and Portable Life Support Systems

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Extravehicular Activity
Risk Number :	37
Risk Description :	EVA performance and crew health may be compromised by inadequate EVA systems.
Context / Risk	This risk may be influenced by flight duration, lack of return and re-supply capability, limited on-

Factors :	board servicing capability, or dust contamination of suit bearings and joints.
Justification / Rationale :	Long-duration crew stays on moon and Mars lead to increased EVA hardware use. Lunar and Mars gravity levels cause suit weight to become a significant load on crewmembers. Hardware failures could occur without the capability for equipment servicing and overhaul. Lunar and Mars dust contamination leads to equipment failures and decreased suit mobility from contaminated bearings and joints
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Dedicated water • Limited maintenance • Longer life rechargeable batteries • Regenerable CO2 removal systems
Projected Countermeasures or Mitigations & other Deliverables:	• Cleaning and maintenance of soft goods (e.g., washing of LCVG) • Dust removal and dust prevention [Lunar] [Mars] • Increased on-orbit space suit service life • Longer shelf and service life batteries • Non-venting heat rejection system • Reduced mass of suit and PLSS [Lunar] [Mars] • Regenerable closed loop CO2 removal systems
Research & Technology Questions [With Mission Priority]:	

No.	Question
37a	What EVA system design and minimum prebreathe protocol can be developed to reduce the risk of decompression sickness? **[ISS N/A, Lunar 1, Mars 1]**
37b	What suit and PLSS technology must be developed to meet mission requirements for EVA mobility? **[ISS N/A, Lunar 1, Mars 1]**
37c	How do we protect against planetary surface dust through suit and airlock system design? **[ISS N/A, Lunar 1, Mars 1]**
37d	How do we protect against toxic fluids and contaminants? **[ISS 2, Lunar 2, Mars 2]**
37e	How do we design space suits to fit multiple crewmembers of various sizes and shapes? **[ISS 1, Lunar 1, Mars 1]**
37f	How do we improve glove dexterity? **[ISS 1, Lunar 1, Mars 1]**
37g	What technologies can be developed to provide passive or active thermal insulation in various environments, including deep-space and lunar vacuum? **[ISS N/A, Lunar 1, Mars 1]**
37h	What technologies must be developed to meet mission non-venting and non-contaminating requirements? **[ISS N/A, Lunar 2, Mars 2]**
37i	How do we provide and manage increased information to EVA crewmembers, including suit parameters, systems status, caution and warning, video, sensor data, procedures, text, and graphics? **[ISS N/A, Lunar 2, Mars 2]**
37j	How do we achieve EVA and robotic interaction and cooperation? **[ISS N/A, Lunar 1, Mars 1]**
37k	What biomedical sensors are needed to enhance safety and performance during EVAs? **[ISS 4, Lunar 2, Mars 2]**
37l	How can space suit design accommodate a crewmember's physical changes from long-duration exposure to microgravity? **[ISS 4, Lunar 1, Mars 1]**

	37m	What technology can be developed to monitor EVA crewmember thermal status and provide auto-thermal control under both nominal operating and emergency conditions? **[ISS N/A, Lunar 1, Mars 1]**
	37n	Can a practical EMU containment receptacle for emesis be developed? If a vomiting episode occurs, is there a way of refurbishing the suit during the mission? How can suit life support systems be designed to be more resistant to vomiting episode? **[ISS 1, Lunar 1, Mars 1]**
Related Risks :		**Environmental Health**
		Define Acceptable Limits for Contaminants in Air and Water
		Sensory-Motor Adaptation
		Motion Sickness
		Clinical Capabilities
		Monitoring and Prevention
		Major Illness and Trauma
		Ambulatory Care
		Medical Informatics, Technologies, and Support Systems
		Advanced Environmental Monitoring & Control
		Monitor External Environment
		Provide Integrated Autonomous Control of Life Support Systems
		Advanced Life Support
		Maintain Thermal Balance in Habitable Areas
		Provide and Maintain Bioregenerative Life Support Systems
Important References :		Advanced Technology for Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington DC, 1997.

Risk Title: Maintain Food Quantity and Quality

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Food Technology
Risk Number :	38
Risk Description :	Crew nutritional requirements may not be met and crew health and performance compromised due to inadequate food acceptability, preparation, processing, and storage systems.
Context / Risk Factors :	This risk may be influenced by sub-standard food intakes, chemical or microbial contamination of food, crew psychological and physiological changes, elevated stress and boredom, inadequate food packaging, inadequate food processing/preservation, inadequate quantity of food, inadequate shelf life, inadequate storage conditions and environmental control, inadequate variety, product formulation, or undefined nutritional requirements.
Justification / Rationale :	There must be means to provide the crew a sufficient, balanced, nutritious diet.
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 3 **Mars:** Priority 1
Current Countermeasures :	• Hazard analysis critical control point processing • Increased menu cycle and menu variety • Menu developed based on daily nutritional requirements

<table>
<tr><td></td><td>

- Preflight food tasting and selection
- Vitamin and nutrient supplementation

</td></tr>
<tr><td>Projected Countermeasures or Mitigations & other Deliverables:</td><td>

- Assessment of food psychosocial importance [TRL 2]
- Determine effects of space radiation on food [TRL 1]
- Development of extended shelf life food through improved food preservation technologies [TRL 2]
- Enhanced food system with increased variety and acceptability [TRL 4]
- Hazard analysis critical control point processing [TRL 4]
- High barrier and low mass food packaging materials [TRL 2]
- Refined nutritional requirements [TRL 4]

</td></tr>
<tr><td>Research & Technology Questions [With Mission Priority]:</td><td>
<table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td>38a</td><td>What procedures (e.g., storage, processing, preparation, clean-up), such as HACCP, need to be developed to assure a safe food system? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>38b</td><td>What are the allowable limits of microbial and chemical contamination in the food? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>38c</td><td>How does space radiation affect the functionality and nutritional content of the crops and stored staple ingredients for food processing? [ISS N/A, Lunar 1, Mars 1]</td></tr>
<tr><td>38d</td><td>What food processing technologies are required when using crops and stored staple ingredients to ensure a food system that is nutritious, safe and acceptable? [ISS N/A, Lunar 1, Mars 1]</td></tr>
<tr><td>38e</td><td>What food packaging materials will provide the physical and chemical attributes, including barrier properties, to protect the food from the outside environment and assure the 3-5 year shelf life? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>38f</td><td>What food packaging material will be biodegradable, easily processed, or be lighter in mass than the current packaging and can still provide the physical and chemical attributes including barrier properties to protect the food from the outside environment and assure the 3-5 year shelf life? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>38g</td><td>What food preservation technologies will provide prepackaged food items with a shelf life of 3-5 years? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>38h</td><td>What are the impacts of reduced Gravity and atmospheric pressure on the food processing activities? [ISS N/A, Lunar 2, Mars 1]</td></tr>
<tr><td>38i</td><td>What are the impacts of reduced Gravity and atmospheric pressure on the food preparation activities? [ISS 3, Lunar 2, Mars 1]</td></tr>
<tr><td>38j</td><td>What nutritional content and sensory attribute changes (including radiation-induced effects) in the prepackaged food items will occur over the shelf life of the food? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>38k</td><td>What food system technology selection criteria will be used to effectively reduce the use of critical resources such as air, water, thermal, biomass and solid waste processing, during a mission? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>38l</td><td>What are the changes (taste, odor, etc.) that occur in crewmember's sensory perceptions during space flight that would affect food acceptability? [ISS 3, Lunar 3, Mars 3]</td></tr>
<tr><td>38m</td><td>What are the physical and chemical requirements for each of the crops and stored staple ingredient items to assure effective processing into acceptable, safe and nutritious food ingredients? [ISS N/A, Lunar 2, Mars 2]</td></tr>
<tr><td>38n</td><td>What level of acceptability and/or variety (e.g., number of food items, length of menu cycle) is required to provide for the psychosocial well-being of the crew? [ISS 3, Lunar 3, Mars 2]</td></tr>
</table>
</td></tr>
</table>

	38o	What modeling techniques can be used to measure the subjective portions of the food system such as palatability, nutrition, psychological issues and variety? **[ISS 3, Lunar 3, Mars 2]**
Related Risks :		**Cardiovascular Alterations**
		Occurrence of Serious Cardiac Dysrhythmias
		Environmental Health
		Define Acceptable Limits for Contaminants in Air and Water
		Immunology & Infection
		Immune Dysfunction, Allergies and Autoimmunity
		Interaction of Space flight Factors, Infections and Malignancy
		Skeletal Muscle Alterations
		Reduced Muscle Mass, Strength, and Endurance
		Nutrition
		Inadequate Nutrition
		Behavioral Health & Performance and Space Human Factors (Cognitive)
		Human Performance Failure Due to Poor Psychosocial Adaptation
		Human Performance Failure Due to Neurobehavioral Problems
		Radiation
		Acute Radiation Risks
		Advanced Environmental Monitoring & Control
		Monitor Surfaces, Food, and Soil
		Advanced Life Support
		Maintain Thermal Balance in Habitable Areas
		Manage Waste
		Provide and Maintain Bioregenerative Life Support Systems
		Provide and Recover Potable Water
Important References :		Isolation NASA Experiments in Closed-Environment Living Advanced Human Life Support Enclosed System Volume 104SCIENCE AND TECHNOLOGY SERIES; A Supplement to Advances in the Astronautical Sciences Edited by: Helen W. Lane, Richard L. Sauer, and Daniel L. Feeback. Published for the American Astronautical Society by Univelt, Incorporated, P.O. Box 28130, San Diego, California 92198 web: http://lsda.jsc.nasa.gov/books/ground/chambers.pdf. web:%20%20http://lsda.jsc.nasa.gov/books/ground/chambers.pdf
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	U. S. Food and Drug Administration. Kinetics of Microbial Inactivation for Alternative Food Processing Technologies. http://vm.cfsan.fda.gov/~comm/ift-toc.html. June 2000. http://vm.cfsan.fda.gov/~comm/ift-toc.html

Risk Title: Maintain Acceptable Atmosphere

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Life Support
Risk Number :	39
Risk Description :	Crew health may be compromised due to inability of currently available technology to monitor and control spacecraft atmosphere. Risk may be mitigated by development of new technologies that will be integrated into the life support systems.
Context / Risk Factors :	This risk may be influenced by complexity of systems and increase in the number of systems (e.g., additional solid waste processing, plant growth, food processing, etc.), insensitivity of control system to contaminants leading to toxic build-ups due to a closed system, remoteness, or severely constrained resources (such as mass, power, volume, thermal, crew time).
Justification / Rationale :	The inability to control and condition the atmosphere and maintain the makeup & composition, limits the ability of the crew to perform basic functions and can present an immediate threat to the health, life and success of crew and mission.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Consumables re-supply • Technology development to further close the air loop and increase carbon dioxide reduction, which includes testing, modeling and analysis
Projected Countermeasures or Mitigations & other Deliverables:	• Bioregenerative Life Support [Lunar] [Mars] • CO2 Moisture Removal System [TRL 4] [Lunar] [Mars] • Improved Carbon Dioxide Removal and Reduction System [TRL 3-4] • In-Situ Resource Utilization [Lunar] [Mars] • Regenerable Trace Contaminant Control System [TRL 4] • Better models to identify contaminant load [Lunar] [Mars]
Research & Technology Questions [With Mission Priority]:	

No.	Question
39a	What new developments are needed to meet all the requirements for controlling trace contaminants, atmospheric pressure, O2 and CO2 partial pressure? **[ISS 1, Lunar 1, Mars 1]**

	<table><tr><td>39b</td><td>What method for closing the O2 loop is most effective in an integrated ECLS? [ISS 2, Lunar 2, Mars 2]</td></tr><tr><td>39c</td><td>What is the proper trace contaminant load and performance model to drive the design and operation of a trace contaminant system? [ISS 2, Lunar 2, Mars 2]</td></tr><tr><td>39d</td><td>Can viability and genetic integrity of the biological components be maintained for the duration of different missions? [ISS 4, Lunar 3, Mars 2]</td></tr><tr><td>39e</td><td>What are the effects of radiation on biological components of the life support system? [ISS 3, Lunar 3, Mars 1]</td></tr><tr><td>39f</td><td>What research is required to validate design approaches for multiphase flow and particulate flows for air revitalization systems in varying gravity environments? [ISS 3, Lunar 3, Mars 3]</td></tr></table>
Related Risks :	<table><tr><td>Environmental Health</td></tr><tr><td>Define Acceptable Limits for Contaminants in Air and Water</td></tr><tr><td>Radiation</td></tr><tr><td>Acute Radiation Risks</td></tr><tr><td>Advanced Environmental Monitoring & Control</td></tr><tr><td>Monitor Air Quality</td></tr><tr><td>Monitor Water Quality</td></tr><tr><td>Monitor Surfaces, Food, and Soil</td></tr><tr><td>Provide Integrated Autonomous Control of Life Support Systems</td></tr><tr><td>Advanced Life Support</td></tr><tr><td>Maintain Thermal Balance in Habitable Areas</td></tr><tr><td>Manage Waste</td></tr><tr><td>Provide and Maintain Bioregenerative Life Support Systems</td></tr></table>
Important References :	<table><tr><td>Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA RP-1324, 1994</td></tr><tr><td>Isolation, NASA Experiments in Closed-Environment Living, Advanced Human Life Support Enclosed System Final Report, Volume 104, Science And Technology Series, A Supplement to Advances in the Astronautical Sciences, Edited by Helen W. Lane, Richard L. Sauer and Daniel L. Feeback. Published for the American Astronautical Society by Univelt, Incorporated, P.O. Box 28130, San Diego, CA 92198. web: http://lsda.jsc.nasa.gov/books/ground/chambers.pdf http://lsda.jsc.nasa.gov/books/ground/chambers.pdf</td></tr><tr><td>Space flight Life Support and Biospherics, Eckart, 1996</td></tr></table>

Risk Title: Maintain Thermal Balance in Habitable Areas

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Life Support
Risk Number :	40
Risk Description :	Crew health may be compromised due to inability of currently available technology to provide crew module thermal control. Risk may be further mitigated by development of new technologies that will be integrated into the thermal control system.
Context / Risk Factors :	This risk may be influenced by location on a planetary surface, orientation of the vehicle during flight, orientation of vehicle and/or habitat on planetary surface, planetary environment (temperature ranges & extremes, dust, seasonal variations, etc.), sources of heat from other elements of the mission, and use or availability of local planetary resources.
Justification / Rationale :	Humans cannot live and work in space without a thermally controlled environment.

Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Thermal Control system
Projected Countermeasures or Mitigations & other Deliverables:	• Several advances are underway to improve the reliability and life, or decrease the mass, volume, or power required for thermal control system hardware (e.g. heat rejection devices, heat transport fluids, heat acquisition devices, heat transfer devices) [TRL 3-6]
Research & Technology Questions [With Mission Priority]:	(see table below)

No.	Question
40a	What heat transport fluids meet the requirements for specified missions? **[ISS 1, Lunar 1, Mars 1]**
40b	What materials and designs will meet the heat acquisition (cold plates, heat exchangers, cooling jackets, etc.) requirements for specified missions? **[ISS 1, Lunar 1, Mars 1]**
40c	What materials and designs will meet the heat transport (pumps, two-phase loops, heat pumps, etc.) requirements for specified missions? **[ISS 1, Lunar 1, Mars 1]**
40d	What materials and designs will meet the heat rejection (radiators, sublimators, evaporators, etc.) requirements for specified missions? **[ISS 1, Lunar 1, Mars 1]**
40e	What materials and designs will meet the humidity control requirements for specified missions? **[ISS 1, Lunar 1, Mars 1]**
40f	What thermal system sensors will meet the requirements to provide monitoring and data collection for specified missions? **[ISS 2, Lunar 2, Mars 2]**
40g	What monitoring and control system hardware and design will meet the requirements for specified missions? (AEMC) **[ISS 2, Lunar 2, Mars 2]**

Related Risks :

Advanced Environmental Monitoring & Control
Monitor Air Quality
Advanced Extravehicular Activity
Provide Space Suits and Portable Life Support Systems
Advanced Life Support
Maintain Acceptable Atmosphere

Important References :

Advanced Technology of Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington DC, 1997.
Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA RP-1234, 1994.
Isolation, NASA Experiments in Closed-Environment Living, Advanced Human Life Support Enclosed System Final Report, Volume 104, Science And Technology Series, A Supplement to Advances in the Astronautical Sciences, Edited by Helen W. Lane, Richard L. Sauer and Daniel L. Feeback. Published for the American Astronautical Society by Univelt, Incorporated, P.O. Box 28130, San Diego, CA 92198. web: http://lsda.jsc.nasa.gov/books/ground/chambers.pdf http://lsda.jsc.nasa.gov/books/ground/chambers.pdf
Space flight Life Support and Biospherics, Eckart, 1996.

Risk Title: Manage Waste

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Life Support
Risk Number :	41

<table>
<tr><td>Risk Description :</td><td>Crew health may be compromised due to inability of currently available technology to adequately process solid wastes reliably with minimum power, mass, volume. Inadequate waste management can also lead to contamination of planetary surfaces.</td></tr>
<tr><td>Context / Risk Factors :</td><td>This risk may be influenced by crew health, crew susceptibility to the degree of system closure, mission duration, the microgravity environment, failure of other systems such as diminished or failed power supply, or remoteness.</td></tr>
<tr><td>Justification / Rationale :</td><td>Inadequate waste management can result in crew health and safety concerns, including reduced performance and sickness. Inadequate waste management can also lead to contamination of planetary surfaces, or significant increases in mission costs in terms of system mass, power, volume and consumables.</td></tr>
<tr><td>Risk Rating :</td><td>ISS: Priority 3
Lunar: Priority 2
Mars: Priority 1</td></tr>
<tr><td>Current Countermeasures :</td><td>Adsorbents are used for odor control
Crew manually compacts waste and/or stores waste in bags
Feces is mechanically compacted
Waste is returned to Earth in the Space Shuttle for disposal, or returned in expendable logistics modules to be destroyed on entry</td></tr>
<tr><td>Projected Countermeasures or Mitigations & other Deliverables:</td><td>Current practice though less than optimal may be adequate for the life of ISS
Provide a system for adequately collecting waste . [TRL 2] [Lunar] [Mars]
Provide a system for adequately transporting waste [TRL 2] [Lunar] [Mars]
Provide a system for processing waste for storage , resource recovery or disposal of trash generated (including clothing) throughout the mission, reliably and efficiently with minimum power, mass and volume. [TRL 2] [Lunar] [Mars]</td></tr>
<tr><td>Research & Technology Questions [With Mission Priority]:</td><td><table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td>41a</td><td>What system will meet the storage and/or disposal requirements for specified missions? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>41b</td><td>What system will meet requirements for processing wastes to recover resources for specified missions? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>41c</td><td>What waste management will handle complex waste streams such as packaging, paper, etc. in order to meet mission requirements? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>41d</td><td>What waste management will handle medical wastes such as blood, tissues and syringes etc. in order to meet mission requirements? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>41e</td><td>What system will meet the requirements for managing residuals for planetary protection? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>41f</td><td>How can microbes and candidate crop species be engineered to perform better and fulfill multiple functions in a bioregenerative system? [ISS 4, Lunar 3, Mars 1]</td></tr>
<tr><td>41g</td><td>What are the interfaces between the biological and physical chemical life support subsystems for a specified mission? [ISS 3, Lunar 3, Mars 1]</td></tr>
<tr><td>41h</td><td>Can viability and genetic integrity of the biological components be maintained for the duration of different missions? [ISS 4, Lunar 3, Mars 2]</td></tr>
<tr><td>41i</td><td>How do partial and microgravity affect biological waste processing? [ISS 4, Lunar 3, Mars 1]</td></tr>
<tr><td>41j</td><td>What are the effects of radiation on biological components of the life support system? [ISS 3, Lunar 3, Mars 1]</td></tr>
<tr><td>41k</td><td>What sensors are required to monitor performance and provide inputs to control systems (AEMC)? [ISS 2, Lunar 2, Mars 2]</td></tr>
</table></td></tr>
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	41l	What monitoring and control system can provide semi to total autonomous control to relieve the crew of monitoring and control functions to the extent possible (AEMC)? **[ISS 2, Lunar 2, Mars 2]**
	41m	What studies need to be performed to determine whether or not recycling of solid waste can be done cost effectively to provide building materials for habitability features needed in subsequent phases of specified missions? **[ISS 5, Lunar 3, Mars 3]**
	41n	What research is required to validate design approaches for multiphase flows for solid waste management and resource recovery in varying gravity environments. **[ISS 3, Lunar 3, Mars 3]**
	41o	What resources are required to manage waste disposal as an environmental risk during long and remote missions (from EH)? **[ISS 4, Lunar 3, Mars 1]**
	41p	What system will meet requirements for processing wastes to recover water for specified missions? **[ISS 1, Lunar 1, Mars 1]**
	41q	What system will meet requirements for processing wastes to recover CO2 for specified missions? **[ISS 1, Lunar 1, Mars 1]**
	41r	What system will meet requirements for processing wastes to recover minerals for specified missions? **[ISS 1, Lunar 1, Mars 1]**
	41s	How should wastes be handled or stored to avoid perception such as bad odors or unsightly appearance that would adversely affect crew quality of life and consequent degradation in performance? **[ISS 2, Lunar 2, Mars 2]**
	41t	What waste management systems will prevent release of biological material (cells or organic chemicals that are signs of life) from contaminating a planetary surface, such as the Martian surface, and compromising the search for indigenous life? **[ISS N/A, Lunar 4, Mars 1]**
	41u	What management systems will prevent release of biological materials that could harm indigenous biological communities? **[ISS 3, Lunar 2, Mars 1]**
	41v	What is the probability that waste materials could become reservoirs for return of indigenous life to Earth (i.e. backward contamination)? What systems can prevent this from occurring? **[ISS N/A, Lunar N/A, Mars 1]**
	41w	What is the probability that microorganisms in biological wastes such as food scraps or feces could be altered or mutated by the space environment radiation to become harmful or pathogenic? What can prevent this? **[ISS 4, Lunar 3, Mars 2]**
	41x	What containment vessels will be sufficient to prevent escape of stored waste at various mission locations such as planetary surfaces or crew cabins? **[ISS 4, Lunar 3, Mars 1]**
Related Risks :		**Immunology & Infection**
		Alterations in Microbes and Host Interactions
		Nutrition
		Inadequate Nutrition
		Radiation
		Acute Radiation Risks
		Advanced Life Support
		Maintain Acceptable Atmosphere
		Provide and Maintain Bioregenerative Life Support Systems
		Provide and Recover Potable Water
Important References :		Advanced Technology of Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington DC, 1997.
		Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA RP-1324, 1994.

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	Space flight Life Support and Biospherics, Eckart, 1996.

Risk Title: Provide and Maintain Bioregenerative Life Support Systems

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Life Support
Risk Number :	42
Risk Description :	Sustaining crew health and performance may be compromised by lack of bioregenerative systems.
Context / Risk Factors :	This risk may be influenced by the effect of radiation on plants, reduced atmospheric pressure, reduced sunlight, limited availability of water, limits on power availability for artificial lighting, reduced gravity, or remoteness.
Justification / Rationale :	For ISS, the re-supply line is relatively short, on-board resources are limited for accommodating bioregenerative systems, and the risk to crew performance and mission success is relatively low. For the moon, bioregenerative systems would be advantageous to sustain long-term habitats on the Lunar surface due to cost and contingencies required for re-supply. For Mars, very high life support resupply costs would be necessary for a long-term Martian habitat without bioregenerative systems. Bioregenerative systems would be the only means of producing food and a primary contributor for CO_2 removal, O_2 production, and H_2O purification and achieving high degree of autonomy.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Development of Vegetable Production Unit • Screen acceptable cultivars for space systems • Fresh fruit and vegetables included on current re-supply missions to ISS
Projected Countermeasures or Mitigations & other Deliverables:	• Integrated Bioregenerative / PC test bed [TRL 3] [Mars] • Low pressure Martian greenhouse [TRL 3] [Mars] • Mixed cropping systems for continuous production evaluated [TRL 5] [Lunar] • Provide Vegetable Production Unit for ISS [TRL 5] • Scale system to meet all O_2 and CO_2 requirements for surface habitat, and to meet partial food requirements. [CRL 6] [Mars] • Scale gravity-based salad production module to meet all water and O_2 requirements for surface missions, and to meet food requirements [TRL 4] [Lunar]
Research & Technology Questions [With Mission Priority]:	

No.	Question
42a	What are the optimal methods of plant growth for a specified mission, including development of appropriate hardware, management of light, water, nutrients, gas composition and pressure, trace contaminants, horticultural procedures and disease risks? **[ISS 2, Lunar 2, Mars 1]**
42b	How can microbes and candidate crop species be engineered to perform better and fulfill multiple functions in a bioregenerative system? **[ISS 4, Lunar 3, Mars 1]**
42c	What mechanized or automated systems are required for planting, harvesting, monitoring, and controlling crops for a specified mission? **[ISS 4, Lunar 3, Mars 2]**

	42d	Can viability and genetic integrity of the biological components be maintained for the duration of different missions? **[ISS 4, Lunar 3, Mars 2]**
	42e	What are the interfaces between the biological and physical chemical life support subsystems for a specified mission? **[ISS 4, Lunar 3, Mars 1]**
	42f	How do partial and microgravity affect plant growth and crop yield? **[ISS 4, Lunar 3, Mars 1]**
	42g	What are the effects of radiation on biological components of the life support system? **[ISS 3, Lunar 3, Mars 1]**
	42h	What percentage of crew food needs should be attributed to ALS plant products for specified missions? **[ISS 5, Lunar 3, Mars 2]**
	42i	What capabilities and associated hardware are required for processing and storing plant products for a specified mission? **[ISS 5, Lunar 3, Mars 2]**
	42j	Can the plant production rates and ALS functions be sustained for the duration of the mission? **[ISS 5, Lunar 3, Mars 1]**
	42k	Can plant yields and ALS functions measured during low TRL (fundamental) testing be scaled up for large bioregenerative systems? **[ISS 5, Lunar 3, Mars 1]**
	42l	What sensors and monitoring systems will be required to measure environmental conditions and crop growth parameters and health for a specified mission (AEMC)? **[ISS 3, Lunar 3, Mars 2]**
	42m	What control system hardware and software technologies will be required to monitor and control crop systems for a specified mission (AEMC)? **[ISS 3, Lunar 3, Mars 2]**
Related Risks :		**Environmental Health**
		Define Acceptable Limits for Contaminants in Air and Water
		Nutrition
		Inadequate Nutrition
		Radiation
		Acute Radiation Risks
		Advanced Environmental Monitoring & Control
		Monitor Air Quality
		Monitor Water Quality
		Provide Integrated Autonomous Control of Life Support Systems
		Advanced Extravehicular Activity
		Provide Space Suits and Portable Life Support Systems
		Advanced Life Support
		Maintain Acceptable Atmosphere
		Manage Waste
		Provide and Recover Potable Water
Important References :		Advanced Technology of Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington DC, 1997.
		Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA RP-1324, 1994.

	Isolation, NASA Experiments in Closed-Environment Living, Advanced Human Life Support Enclosed System Final Report, Volume 104, Science And Technology Series, A Supplement to Advances in the Astronautical Sciences, Edited by Helen W. Lane, Richard L. Sauer and Daniel L. Feeback. Published for the American Astronautical Society by Univelt, Incorporated, P.O. Box 28130, San Diego, CA 92198. web: http://lsda.jsc.nasa.gov/books/ground/chambers.pdf http://lsda.jsc.nasa.gov/books/ground/chambers.pdf
	Space flight Life Support and Biospherics, Eckart, 1996.
	Wheeler RM, CL Mackowiak, GS Stutte, NC Yorio, LM Ruffe, JC Sager, RP Prince, BV Peterson, GD Goins, WL Berry, CR Hinkle and WM Knott. 2003. Crop production for Advanced Life Support Systems. Observations from the Kennedy Space Center Breadboard Project. NASA Tech. Mem. 2003-211184. (58 pages).
	Wheeler RM, GW Stutte, GV Subbarao and NC Yorio. 2001. Plant growth and human life support for space travel. In: M. Pessarakli (ed.), 2nd Edition. Handbook of Plant and Crop Physiology. pp. 925-941. Marcel Dekker Inc., NY.
	Wheeler, R.M. and C. Martin-Brennan. 2000. Martian greenhouses: Concept and Challenges. Proceedings from a 1999 Workshop. NASA Tech. Memorandum 208577.

Risk Title: Provide and Recover Potable Water

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Life Support
Risk Number :	43
Risk Description :	Crew health may be compromised due to inability of currently available technology to adequately provide and recover potable water.
Context / Risk Factors :	This risk may be influenced by crew health, crew susceptibility to the degree of system closure, or remoteness.
Justification / Rationale :	Lack of potable water is a health risk. For Lunar and Mars missions, the lack of immediate re-supply and increased reliance on water recovery systems compounds the risk.
Risk Rating :	**ISS:** Priority 3 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• Stored potable water onboard spacecraft • Water recovery system performance monitored • Re-supply of potable water from Earth
Projected Countermeasures or Mitigations & other Deliverables:	• Biological systems [TRL 4] • Possibility of in-situ resource utilization (cannot assign TRL until presence of water is confirmed) • Redundant systems [TRL 2]
Research & Technology Questions [With Mission Priority]:	

No.	Question
43a	What system meets all requirements for supplying potable water needs? **[ISS 1, Lunar 1, Mars 1]**
43b	What mechanisms to collect and transport wastewater meet the mission requirements? **[ISS 1, Lunar 1, Mars 1]**
43c	What methods for the removal of organic, inorganic and microbial contaminants in wastewater meet all mission requirements for efficiency and reliability? **[ISS 1, Lunar 1, Mars 1]**
43d	What method to store and maintain portability of recycled water meets all requirements for specified missions? **[ISS 1, Lunar 1, Mars 1]**

	43e	What sensors are required to provide water quality parameters, monitor performance and provide inputs to a control system (AEMC)? **[ISS 2, Lunar 2, Mars 2]**
	43f	What control system meets all mission requirements (AEMC)? **[ISS 2, Lunar 2, Mars 2]**
	43g	How can microbes be engineered to perform better and fulfill multiple functions in a bioregenerative system? **[ISS 5, Lunar 3, Mars 1]**
	43h	What are the interfaces between the biological and physical chemical life support subsystems for a specified mission? **[ISS 5, Lunar 3, Mars 1]**
	43i	Can viability and genetic integrity of the biological components be maintained for the duration of different missions? **[ISS 5, Lunar 3, Mars 2]**
	43j	How do partial gravity and microgravity affect biological water processing? **[ISS N/A, Lunar 3, Mars 1]**
	43k	What are the effects of radiation on biological components of the life support system? **[ISS 3, Lunar 3, Mars 1]**
	43l	What research is required to validate design approaches for multiphase flows for Water recovery systems in varying gravity environments? **[ISS 1, Lunar 1, Mars 2]**
Related Risks :	**Nutrition**	
	Inadequate Nutrition	
	Radiation	
	Acute Radiation Risks	
	Advanced Environmental Monitoring & Control	
	Monitor Water Quality	
	Provide Integrated Autonomous Control of Life Support Systems	
	Advanced Life Support	
	Manage Waste	
	Provide and Maintain Bioregenerative Life Support Systems	
Important References :	Advanced Technology of Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington DC, 1997.	
	Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA RP-1234, 1994.	
	Isolation, NASA Experiments in Closed-Environment Living, Advanced Human Life Support Enclosed System Final Report, Volume 104, Science And Technology Series, A Supplement to Advances in the Astronautical Sciences, Edited by Helen W. Lane, Richard L. Sauer and Daniel L. Feeback. Published for the American Astronautical Society by Univelt, Incorporated, P.O. Box 28130, San Diego, CA 92198. web: http://lsda.jsc.nasa.gov/books/ground/chambers.pdf http://lsda.jsc.nasa.gov/books/ground/chambers.pdf	
	Space flight Life Support and Biospherics, Eckart, 1996.	

Risk Title: Mismatch Between Crew Physical Capabilities and Task Demands

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Space Human Factors Engineering
Risk Number :	44
Risk Description :	Human performance failure may occur due to human factors inadequacies in the physical work environments (e.g., workplaces, equipment, protective clothing, tools and tasks).
Context / Risk Factors :	Physical elements such as habitats, work environments, equipment, protective clothing, or tools can impact human performance in accomplishing tasks. Additionally, tasks not designed to

<table>
<tr><td></td><td>accommodate human physical limitations, including changes in crew capabilities resulting from mission and task duration factors, may lead to crew injury or illness or reduced effectiveness or efficiency in nominal or predictable emergency situations. Performance may be further affected by state of fitness (and effectiveness of exercise countermeasures), training, and changing gravitational fields.</td></tr>
<tr><td>Justification / Rationale :</td><td>Crew accommodations are designed based primarily on volume and mass considerations. Anecdotal information from crew reports and extrapolations from physiological studies is available on impacts of habitats, work environments, workplaces, equipment, protective clothing, tools and tasks on human performance in space contexts. There is inadequate data on physical performance changes in strength, stamina and motor skill as functions of time in space flight environments. Returning crewmembers usually exhibit substantial physical and motor deficits. Performance will be enhanced through incorporation of human factors into vehicle, task and equipment design.</td></tr>
<tr><td>Risk Rating :</td><td>ISS: Priority 2
Lunar: Priority 2
Mars: Priority 1</td></tr>
<tr><td>Current Countermeasures :</td><td>• Appropriate mission design
• Crew resiliency
• Crew training</td></tr>
<tr><td>Projected Countermeasures or Mitigations & other Deliverables:</td><td>• Measurement, analysis, modeling and design tools for optimizing environment, habitat, workplace, equipment, protective clothing and task design [TRL 2]
• Tools for analyzing physical tasks to determine allocations of functions between humans and machines [TRL 2]</td></tr>
<tr><td>Research & Technology Questions [With Mission Priority]:</td><td>
<table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td>44a</td><td>What are the effects of microgravity, 1/6-gravity, or 1/3-gravity on requirements for habitable volume and architecture? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>44b</td><td>What designs of workspace, equipment, tool and clothing will accommodate differences in crew anthropometry? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>44c</td><td>What are the effects of duration of exposure to microgravity, 1/6-gravity, 1/3-gravity on human physical performance? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>44d</td><td>What tools, equipment and procedures will enable crew physical performance to accommodate the effects of exposure to different gravity levels? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>44e</td><td>How can crewmembers and ground support personnel detect and compensate for decreased physical readiness to perform during a mission? [ISS 2, Lunar 3, Mars 3]</td></tr>
<tr><td>44f</td><td>What scheduling constraints are required to reduce the risk of human performance failure due to physical fatigue to an acceptable probability? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>44g</td><td>What principles of task design and function allocation will result in operations concepts that meet crew performance requirements for the mission? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>44h</td><td>What limitations are required on physical workload to enable crewmembers to complete physical tasks with an acceptable probability? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>44i</td><td>What crew size, composition and task allocations are required to accomplish the reference missions? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>44j</td><td>What design considerations are needed to accommodate effects of changes in gravity, including launch, reentry, lunar landing, lunar launch, Mars landing, Mars launch, and Earth return? [ISS 1, Lunar 1, Mars 1]</td></tr>
</table>
</td></tr>
<tr><td>Related Risks :</td><td>
<table>
<tr><td>Environmental Health</td></tr>
<tr><td>Define Acceptable Limits for Contaminants in Air and Water</td></tr>
<tr><td>Sensory-Motor Adaptation</td></tr>
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	Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation Motion Sickness **Behavioral Health & Performance and Space Human Factors (Cognitive)** Mismatch between Crew Cognitive Capabilities and Task Demands Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems **Advanced Environmental Monitoring & Control** Monitor Air Quality Provide Integrated Autonomous Control of Life Support Systems **Space Human Factors Engineering** Poorly Integrated Ground, Crew, and Automation Functions
Important References :	An Ergonomics Case Study: Manual Material Handling in Microgravity. M. Whitmore & T. D. McKay. Advances in Industrial Ergonomics and Safety VI. London: Taylor & Francis. 1994. Ergonomic Evaluation of a Spacelab Glovebox. M. Whitmore, T. D. McKay, & F. E. Mount. International Journal of Industrial Ergonomics, 16, pp. 155-164. 1995. Human Space flight: Mission Analysis and Design, eds. W.J. Larson, L.K. Pranke. McGraw Hill Space Technology Series. 1999. Set Phasers on Stun, S. Casey, Agean Publishing, 1993. Thornton WE, and Rummel JA. (1977). "Muscular Deconditioning and its Prevention in Space flight," Biomedical Results from Skylab, pp. 175-182, NASA SP-377. Webb Associates, (1978), Anthropometric Source Book, Vol. I. Anthropometry for Designers, pp. 1-76, NASA RP 1024. West JB. (2000). Physiology in microgravity. Journal of Applied Physiology. 89(1): 379-384. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=10904075

Risk Title: Poorly Integrated Ground, Crew, and Automation Functions

Crosscutting Area :	Advanced Human Support Technologies (AHST)
Discipline :	Space Human Factors Engineering
Risk Number :	45
Risk Description :	Mission performance failure may occur without adequate operational concepts, design requirements, and design tools for integration of multiple factors that affect mission performance, such as ground-crew interaction, communication time, and level of automation.
Context / Risk Factors :	This risk may be influenced by communication lag times, communication blackouts, or loss of skills due to extended time since training.
Justification / Rationale :	Inadequate design of human-automation systems is known to lead to human error, based on analysis of incidents in the nuclear power industry and commercial aviation (Evidence Level 3). "Mode error" has resulted in fatal accidents in commercial aviation (Evidence Level 2). At least two critical collisions between ISS and SRMS have been avoided only by real-time monitoring and intervention by mission control (Evidence Level 4).
Risk Rating :	**ISS:** Priority 2 **Lunar:** Priority 2 **Mars:** Priority 1
Current Countermeasures :	• None (ad hoc engineering judgment is used)
Projected	

Countermeasures or Mitigations & other Deliverables:

- Reliability measures and data for human performance [TRL 2]
- Requirements for use of automated systems and for human-centered system design [TRL 2]
- Tools for analyzing task requirements [TRL 2]

Research & Technology Questions [With Mission Priority]:

No.	Question
45a	What crew size and composition is required to accomplish the reference mission? (Shared - Integrated Testing supports) **[ISS 2, Lunar 1, Mars 1]**
45b	What principles and algorithms for allocating tasks to human crewmembers, ground support and onboard automated systems will reduce the probability of significant errors? (Shared - Integrated Testing supports) **[ISS 1, Lunar 1, Mars 1]**
45c	What automated tools and equipment are required to enable the crewmembers to accomplish the mission? **[ISS 2, Lunar 2, Mars 2]**
45d	How do crew size, communications restrictions, crew skills, scheduling constraints and reference mission task requirements affect the requirements for automation? **[ISS 1, Lunar 1, Mars 1]**
45e	What combinations of crew, ground and on-board automation capabilities will increase the likelihood of a successful mission? (Shared - Integrated Testing supports) **[ISS 1, Lunar 1, Mars 1]**
45f	What training and operational readiness assurance processes and implementations will increase likelihood of mission success? **[ISS 2, Lunar 2, Mars 2]**
45g	What principles of task assignment workload and automation need to be developed to facilitate critical team performance? **[ISS 2, Lunar 2, Mars 2]**
45h	What tools and procedures are needed to determine the appropriate level of automation and crew control for the various tasks in the reference missions? **[ISS 1, Lunar 1, Mars 1]**

Related Risks :

Clinical Capabilities
Medical Informatics, Technologies, and Support Systems
Medical Skill Training and Maintenance
Behavioral Health & Performance and Space Human Factors (Cognitive)
Human Performance Failure Due to Poor Psychosocial Adaptation
Human Performance Failure Due to Neurobehavioral Problems
Mismatch between Crew Cognitive Capabilities and Task Demands
Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems
Advanced Environmental Monitoring & Control
Provide Integrated Autonomous Control of Life Support Systems
Space Human Factors Engineering
Mismatch Between Crew Physical Capabilities and Task Demands

Important References :

Billings CE. Aviation Automation: The search for a human-centered approach. Erlbaum: 1997.
Ellis SR. Collision in space. Ergonomics in Design 8(1): 4-9, 2000. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12162316
Human Performance Measures Handbook V.J.Gawron. Lawrence Erlbaum Associates: 2000.
Human Space flight: Mission Analysis and Design, eds. W.J. Larson, L.K. Pranke. McGraw Hill Space Technology Series. 1999.
Normal Accidents, Charles Perrow. 2001.
Sheridan TB. Humans and Automation: System Design and Research Issues. Wiley: 2003.

	The Effect of Automated Intelligent Advisors on Human Decision-making in Monitoring Complex Mechanical Systems. K O'Brien, EM Feldman, & FE Mount. Proceedings of HCI International 1993: 5th International Conference on Human-Computer Interaction. Elsevier Science Publishers. 1993.

Appendix B: Space Flight Factor Interactions

Research and Technology Questions Influenced by Multiple Space Flight Factor Interactions										
R&TQs	Research & Technology Question	ENV	IMM	NUT	PHAR M	PHYSIO	PSYC	RAD	SLEEP	STRESS
1g	What are the important predictors for estimating site-specific bone loss and fracture risk during hypogravity exposure, including, but not limited to ethnicity, gender, genetics, age, baseline bone density and geometry, nutritional status, fitness level and prior microgravity exposure?	X		X		X				
1h	Does the hypogravity environment change the nutritional requirements for optimal bone health?	X		X		X				
1j	What systemic adaptations to hypogravity are important contributory factors to bone loss, evaluations of which are essential for effective countermeasure development (e.g., fluid shifts, altered blood flow, immune system adaptations)?	X	X			X				
5b	What conditions of space flight (e.g., microgravity, disruption of physiological rhythms, nutrition, environmental factors and radiation) may be responsible for cardiac dysrhythmias, and what are the mechanisms involved?	X		X		X		X	X	X
6f	What are the physiological and environmental factors by which space flight decreases orthostatic tolerance?	X				X				
6k	What are the physiological and environmental factors by which space flight decreases aerobic exercise capacity?	X				X				
7g	What impact do space flight-induced biological, physiological, and immunological changes have on the susceptibility of crewmembers to infectious agents and toxic substances in the air and water?	X	X			X				
8a	What are the molecular and genetic mechanisms that are affected by space flight-related environments (e.g., radiation, microgravity, stress, isolation, sleep deprivation, extreme environments, nutritional deficiency, and social interactions) that can result in the loss of immunoregulation/immune tolerance and/or affect innate/acquired immunity, respectively?	X	X	X		X	X	X	X	X
8b	Can the effects on immune function (innate/acquired immunity), or dysfunction (loss of tolerance/immune surveillance) be summarized as a consequence of the conditions relating to each mission and/or its duration (i.e., 1-year ISS, 30-day lunar, 30-month Mars)?	X	X	X		X		X	X	X
9a	What types of latent infections (e.g., viral infections) will become reactivated as a function of space flight-associated factors and pose the greatest threat to human health as a function of compromised immunity resulting from space travel?	X	X	X		X		X	X	X

Research and Technology Questions Influenced by Multiple Space Flight Factor Interactions

R&TQs	Research & Technology Question	ENV	IMM	NUT	PHARM	PHYSIO	PSYC	RAD	SLEEP	STRESS
9d	Will the severity of disease(s) resulting from latent infection reactivation, and/or infections caused by commensal organisms (as a function of space flight-associated factors), be affected by the space mission and/or its duration (i.e., 1-year ISS, 30-day lunar, 30-month Mars)?	X	X	X		X		X	X	X
9e	Are there neoplastic malignancies that may result from latent infection reactivation, and/or infections caused by commensal organisms (as a function of space flight-associated factors), that will be affected by the space mission and/or its duration?	X	X	X		X		X	X	X
9f	Is it possible to predict the summary effects of each component condition and duration of space flight that results in an infectious and/or neoplastic state?	X	X	X		X		X	X	X
10b	Does the spacecraft environment exert a selective pressure on microorganisms that presents the crew with increased health risks (e.g., Helicobacter and ulcers)?	X	X					X		
11g	What are the effects of skeletal muscle atrophy on whole body metabolism (e.g., insulin and glucose tolerance) during space flight?					X				
11h	What are the effects of skeletal muscle atrophy on thermoregulation during space flight?					X				
11n	Is the capacity of skeletal muscle to grow or regenerate (satellite cells) compromised during or after a mission because of conditions (e.g., radiation exposure, reduced skeletal muscle tension)?					X		X		
11t	To what extent do alterations in the sensory-motor system contribute to deficits in skeletal muscle strength and endurance during space flight?					X				
14o	What are the relative contributions of sensory-motor adaptation, neuromuscular deconditioning, and orthostatic intolerance to postflight neuro-motor coordination, ataxia, and locomotion difficulties?					X				X
16b	What are the potential impacts of countermeasures on nutritional requirements or nutritional status?			X		X				
16g	Can general nutrition, or specific nutrient countermeasures, mitigate the negative effects of space flight on bone, muscle, cardiovascular and immune systems, and protect against damage from radiation?		X	X		X		X		
16k	Can general, or specific nutrient countermeasures, mitigate radiation induced carcinogenesis or cataractogenesis?			X		X		X		

Research and Technology Questions Influenced by Multiple Space Flight Factor Interactions

R&TQs	Research & Technology Question	ENV	IMM	NUT	PHARM	PHYSIO	PSYC	RAD	SLEEP	STRESS
17k	What are the primary, secondary and tertiary prevention strategies needed to mitigate the risk of anticipated environmental exposures to radiation and toxic substances (i.e. shielding, nutritional and medical prophylaxis such as agents to augment cellular defenses, immune surveillance, etc.)?		X	X	X	X		X		
18k	What are the nutritional requirements for adequate red cell production in microgravity? What are the contributory factors and how do they inter-relate in the development of space anemia (radiation, unloading, nutrition, fluid shift, changes in sex hormones, etc.)?	X	X	X	X	X		X		
18w	What are the risk factors that can increase the likelihood of DCS, such as the presence of Patent Foramen Ovale (PFO)?	X				X				
18z	What is the role of individual susceptibility, age and gender on the risk of DCS during NASA operations involving decompression?					X				
18ag	What secondary prevention strategies (i.e. countermeasures) should be developed and implemented to prevent adverse reactions to toxic exposures (e.g., sleep, nutrition, medication, stress reduction, shielding, protective equipment, etc.)?	X		X	X			X	X	X
19a	What are the effects of space flight and reduced-G on the absorption, distribution, metabolism, clearance, excretion, clinical efficacy, side effects and drug interactions for medications used in primary, secondary and tertiary prevention of conditions stated in the Space Medicine Condition List?	X		X		X				
24a	What are the fundamental behavioral and social stressors during long-duration missions that will most likely affect crew performance, both individual and team, and how can they be studied for elimination or accomodation in Earth analogue environments?			X		X	X		X	X
24b	What factors contribute to the breakdown of individual/team performance and mission support coordination with regard to scheduling, prioritization of work activities, and control of timelines?						X		X	X
25b	What are the long-term effects of exposure to the space environment (microgravity, isolation, stress) on human neurocognitive and neurobiological functions (from cellular to behavioral levels of the nervous system)?	X	X			X	X			X
25c	What are the long-term effects of exposure to the space environment on human emotion and psychological responses, including emotional reactivity, stress responses, long-term modulation of mood and vulnerability to affective and cognitive disorders?	X					X		X	X
26b	What is required to counteract the negative effects of communications lags on human performance?						X			X

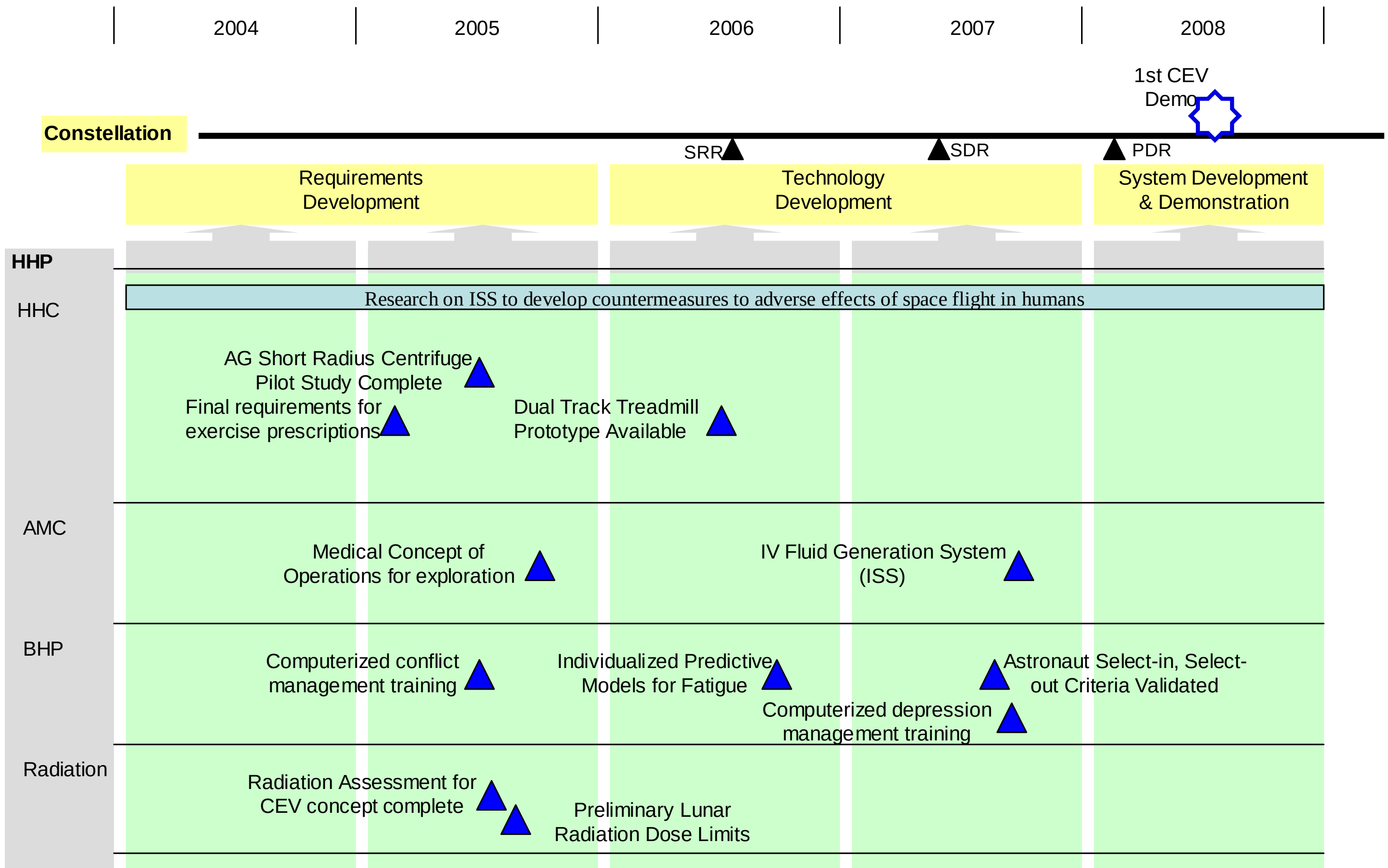
Research and Technology Questions Influenced by Multiple Space Flight Factor Interactions

R&TQs	Research & Technology Question	ENV	IMM	NUT	PHARM	PHYSIO	PSYC	RAD	SLEEP	STRESS
27a	What are the acute and long-term effects of exposure to the space environment on biological rhythmicity, sleep architecture (quantity and quality), and their relationship to performance capability?	X				X	X		X	X
27e	What work, workload, and sleep schedule(s) will best enhance crew performance and mitigate adverse effects of the space environment?								X	X
28e	What are the most effective biomedical or dietary countermeasures to mitigate cancer risks? By what mechanisms are the countermeasures expected to work, and do they have the same efficiency for low- and high-LET radiation?			X	X			X		
28h	Are there significant combined effects from other space flight factors (microgravity, stress, altered circadian rhythms, changes in immune responses, viral reactivation etc.) that modify the carcinogenic risk from space radiation?	X	X			X		X	X	X
29f	Are there significant CNS risks from combined space radiation and other physiological or space flight factors (e.g., bone loss, microgravity, immune-endocrine systems or other)?	X	X			X		X		
31b	Are there synergistic effects arising from other space flight factors (microgravity, stress, immune status, bone loss, damage to intestinal cells reducing their ability to absorb medication etc.) that modify acute risks from space radiation including modifying thresholds for such effects?	X	X	X		X		X		X
38j	What nutritional content and sensory attribute changes (including radiation-induced effects) in the prepackaged food items will occur over the shelf life of the food?	X		X		X	X	X		
39e	What are the effects of radiation on biological components of the life support system? (Maintain Acceptable Atmosphere)	X				X		X		
41j	What are the effects of radiation on biological components of the life support system? (Waste)	X				X		X		
41w	What is the probability that microorganisms in biological wastes such as food scraps or feces could be altered or mutated by the space environment radiation to become harmful or pathogenic? What can prevent this?	X	X			X		X		
42g	What are the effects of radiation on biological components of the life support system? (Bio-regenerative Life Support Systems)	X	X			X		X		
43k	What are the effects of radiation on biological components of the life support system? (Potable Water Systems)	X	X			X		X		

Appendix C: Exploration Systems Mission Directorate Schedules and Milestones

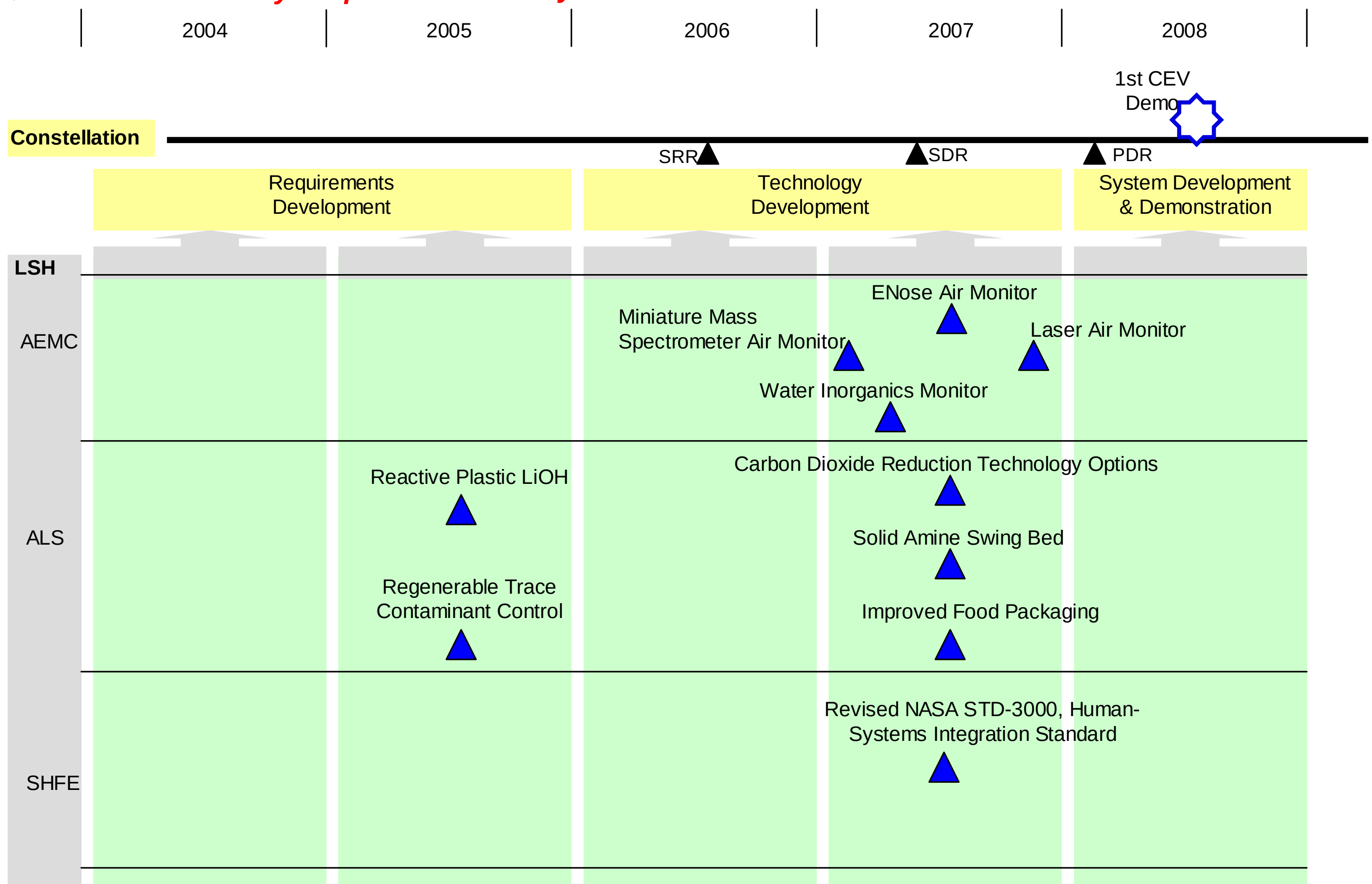
FY05-07 HHP Deliverables

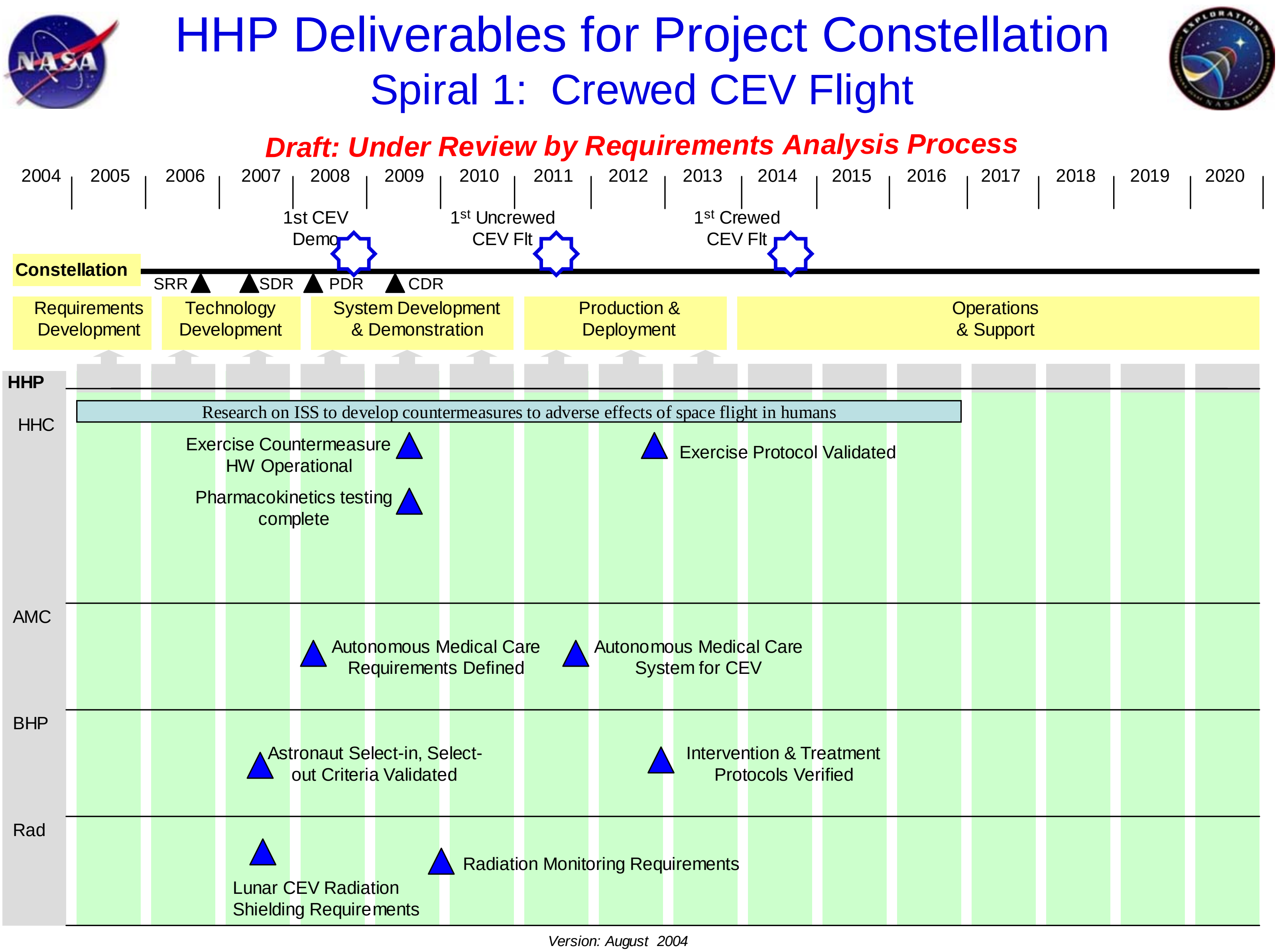
Draft: Under Review by Requirements Analysis Process



FY05-07 LSH Deliverables

Draft: Under Review by Requirements Analysis Process




HHP Deliverables for Project Constellation
Spiral 1: Crewed CEV Flight
Draft: Under Review by Requirements Analysis Process
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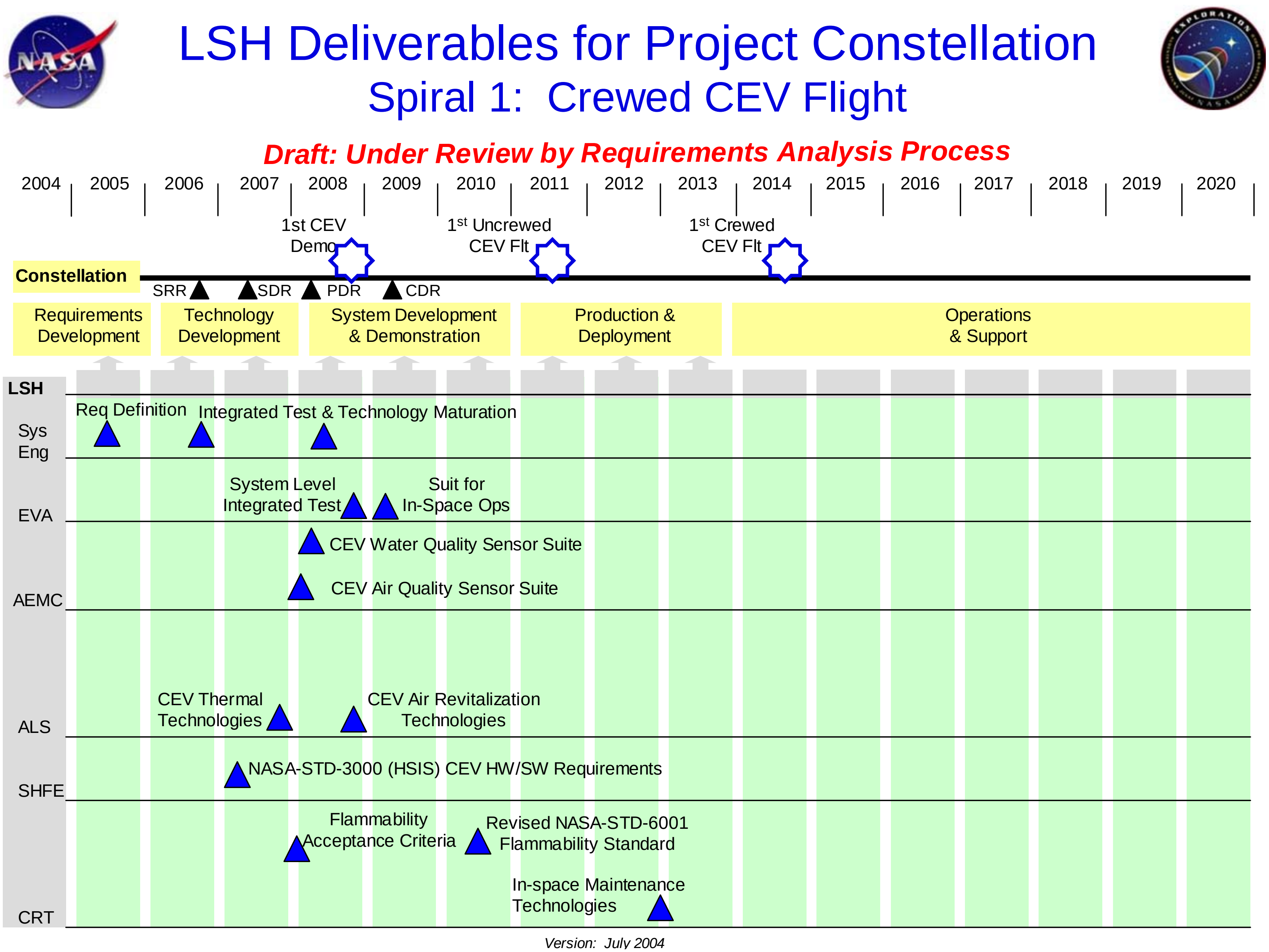
1st CEV Demo
1st Uncrewed CEV Flt
1st Crewed CEV Flt
Constellation
SRR
SDR
PDR
CDR
Requirements Development
Technology Development
System Development & Demonstration
Production & Deployment
Operations & Support
HHP
HHC
Research on ISS to develop countermeasures to adverse effects of space flight in humans
Exercise Countermeasure HW Operational
Exercise Protocol Validated
Pharmacokinetics testing complete
AMC
Autonomous Medical Care Requirements Defined
Autonomous Medical Care System for CEV
BHP
Astronaut Select-in, Select-out Criteria Validated
Intervention & Treatment Protocols Verified
Rad
Radiation Monitoring Requirements
Lunar CEV Radiation Shielding Requirements
Version: August 2004


LSH Deliverables for Project Constellation
Spiral 1: Crewed CEV Flight
Draft: Under Review by Requirements Analysis Process
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Constellation
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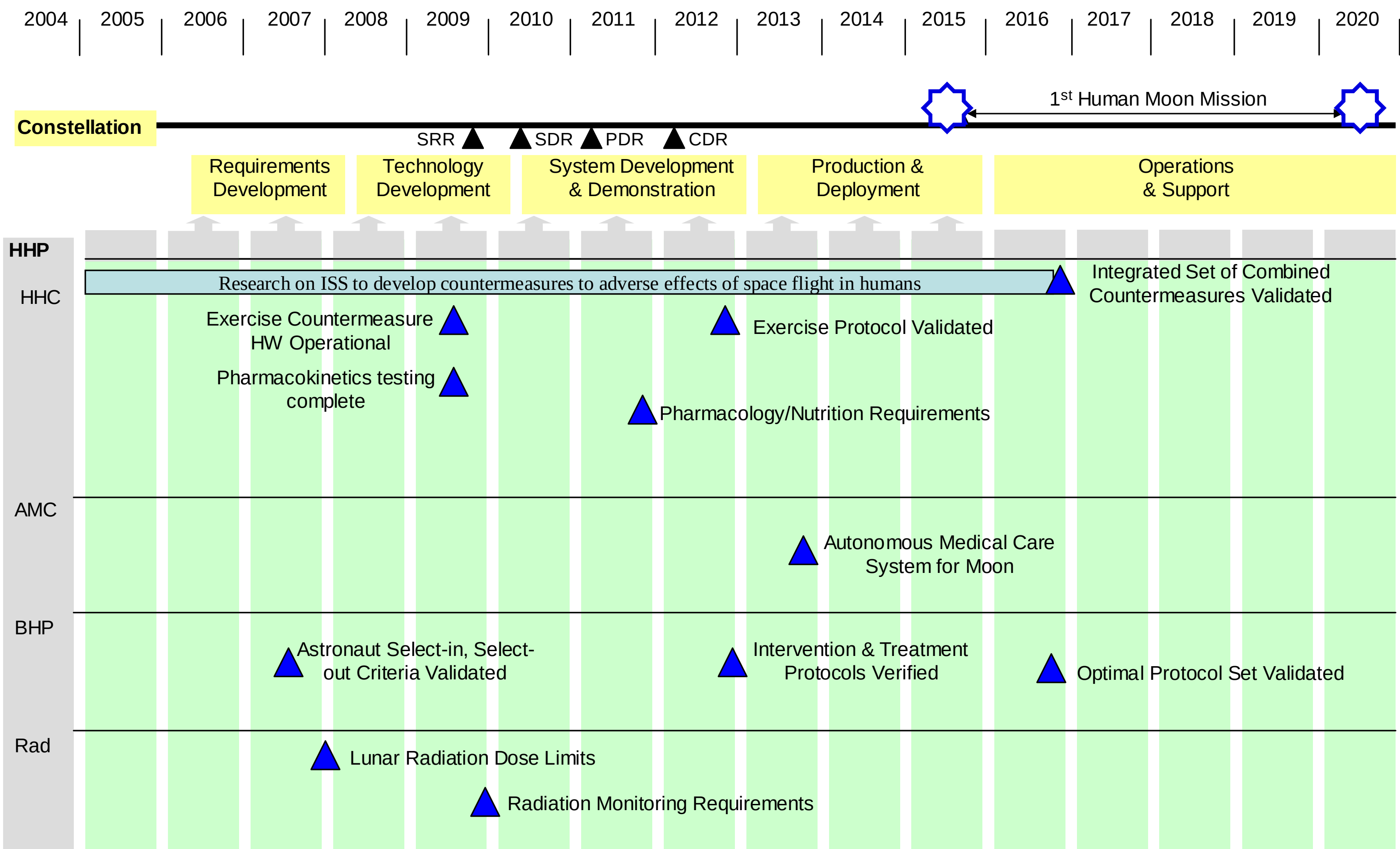
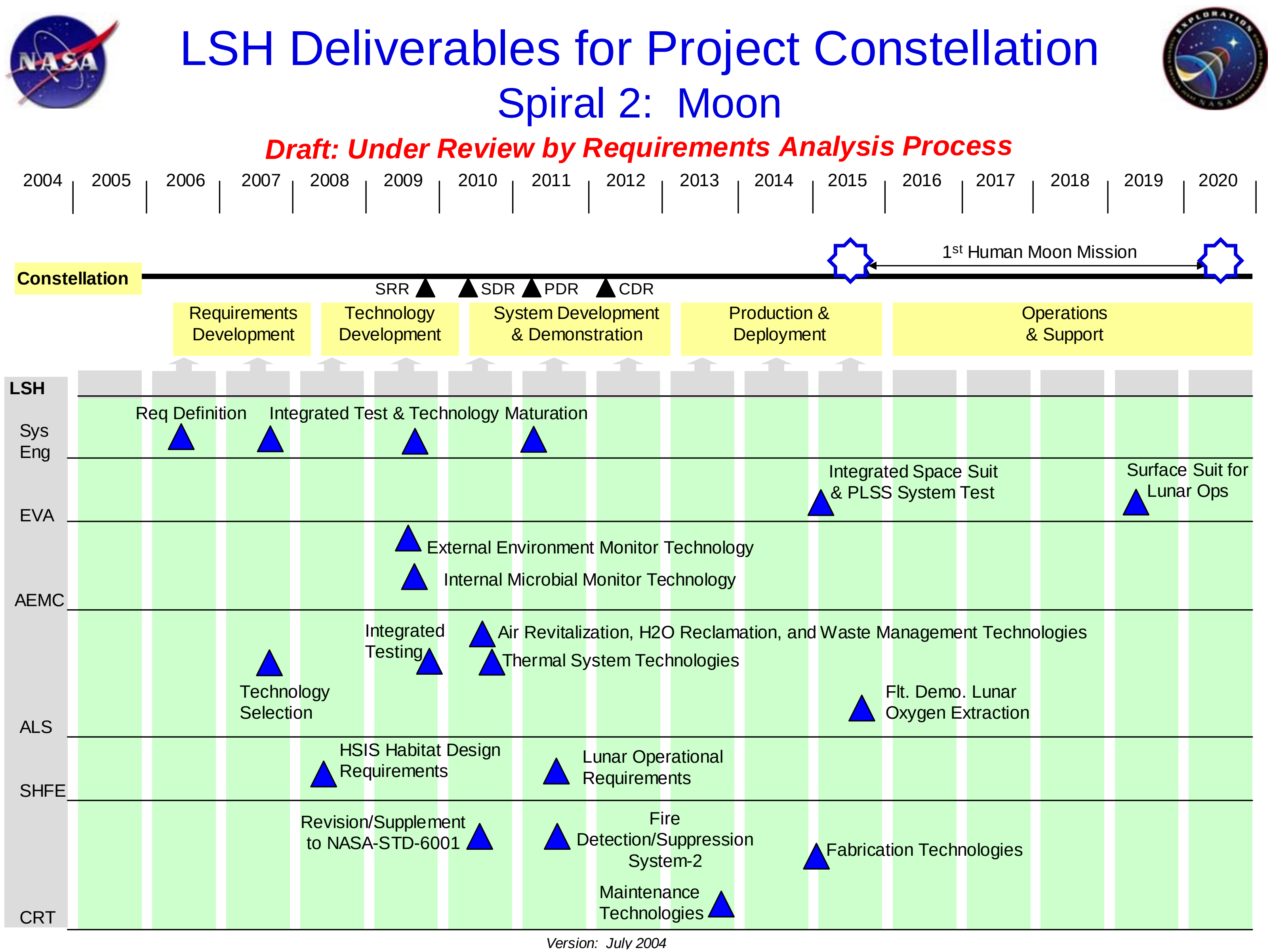
SDR
PDR
CDR
Requirements Development
Technology Development
System Development & Demonstration
Production & Deployment
Operations & Support
LSH
Sys Eng
Req Definition
Integrated Test & Technology Maturation
EVA
System Level Integrated Test
Suit for In-Space Ops
AEMC
CEV Water Quality Sensor Suite
CEV Air Quality Sensor Suite
ALS
CEV Thermal Technologies
CEV Air Revitalization Technologies
SHFE
NASA-STD-3000 (HSIS) CEV HW/SW Requirements
CRT
Flammability Acceptance Criteria
Revised NASA-STD-6001 Flammability Standard
In-space Maintenance Technologies
Version: July 2004

HHP Deliverables for Project Constellation
Spiral 2: Moon

Draft: Under Review by Requirements Analysis Process



Version: August 2004


LSH Deliverables for Project Constellation
Spiral 2: Moon
Draft: Under Review by Requirements Analysis Process
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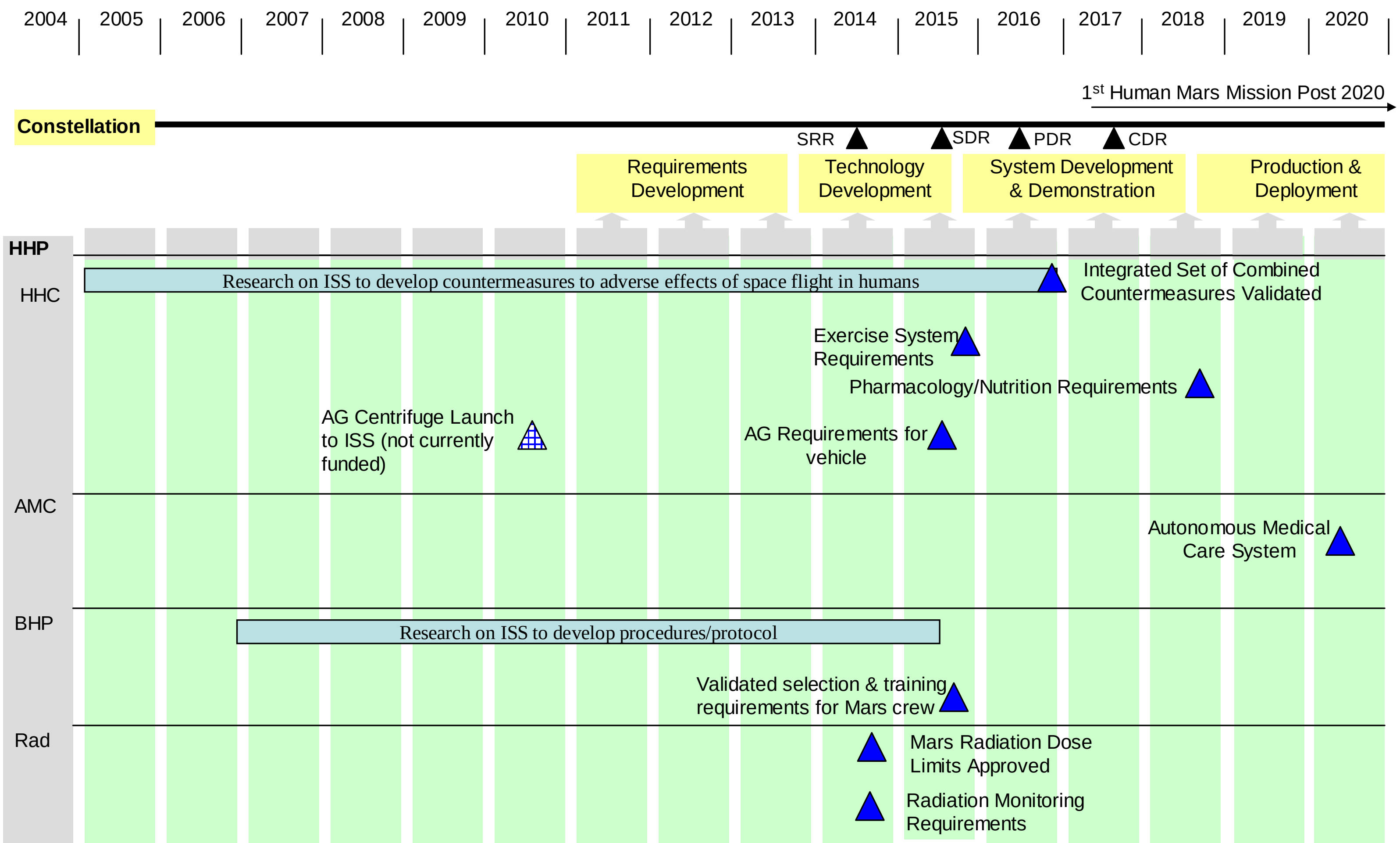
1st Human Moon Mission
Constellation
SRR
SDR
PDR
CDR
Requirements Development
Technology Development
System Development & Demonstration
Production & Deployment
Operations & Support
LSH
Sys Eng
Req Definition
Integrated Test & Technology Maturation
EVA
Integrated Space Suit & PLSS System Test
Surface Suit for Lunar Ops
AEMC
External Environment Monitor Technology
Internal Microbial Monitor Technology
ALS
Integrated Testing
Air Revitalization, H2O Reclamation, and Waste Management Technologies
Thermal System Technologies
Technology Selection
Flt. Demo. Lunar Oxygen Extraction
SHFE
HSIS Habitat Design Requirements
Lunar Operational Requirements
CRT
Revision/Supplement to NASA-STD-6001
Fire Detection/Suppression System-2
Fabrication Technologies
Maintenance Technologies
Version: July 2004

HHP Deliverables for Project Constellation

Spiral N: Mars

Draft: Under Review by Requirements Analysis Process

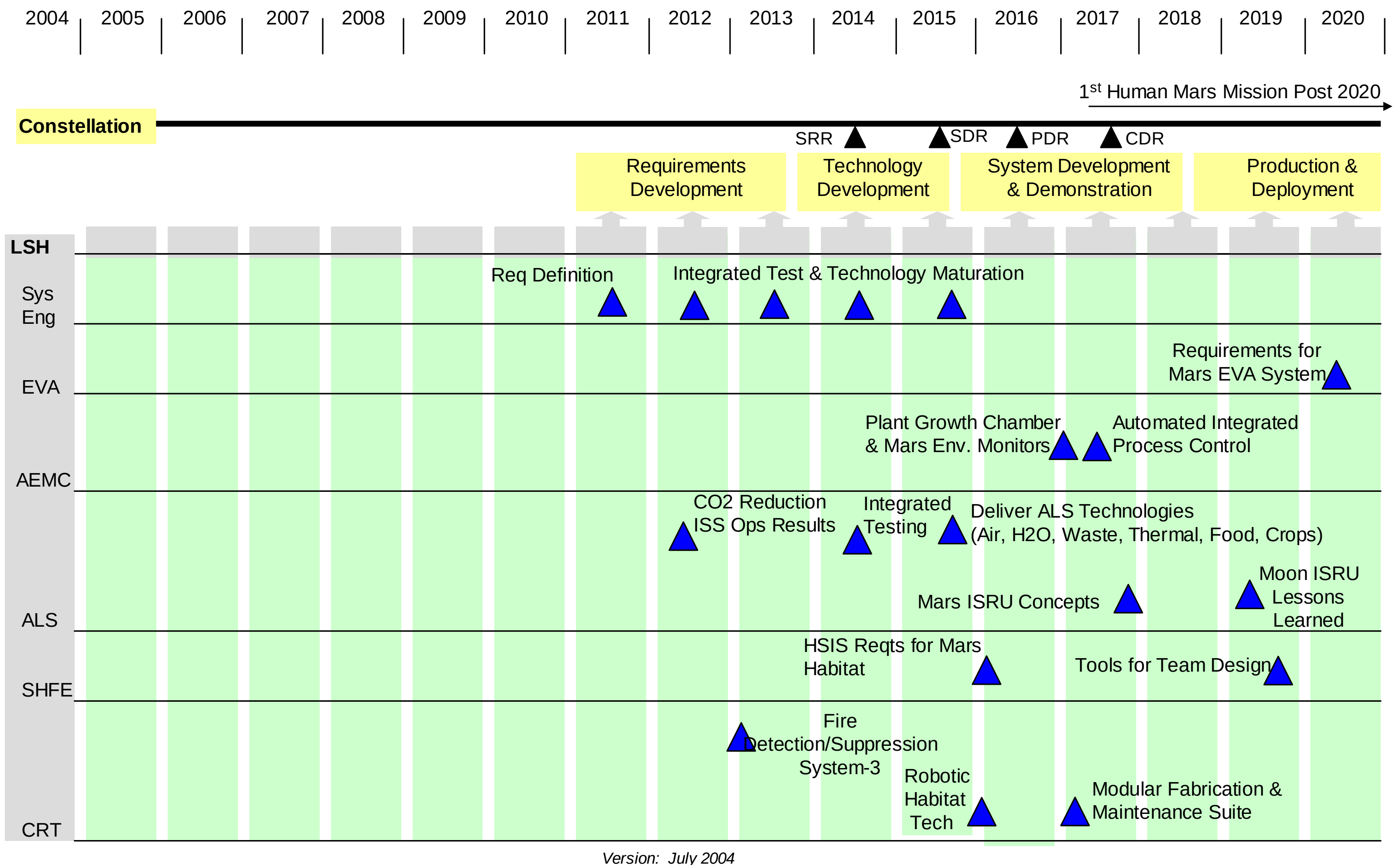


Version: August 2004

LSH Deliverables for Project Constellation

Spiral N: Mars

Draft: Under Review by Requirements Analysis Process



Appendix D: Acronyms

ACRONYMS

0-G	Zero Gravity
1-G/1 X G	One Gravity/Earth Gravity
ACLS	Advanced Cardiac Life Support
AEMC	Advanced Environmental Monitoring and Control
AEVA	Advanced Extravehicular Activity
AFT	Advanced Food Technology
AG	Artificial Gravity
AHST	Advanced Human Support Technology
AIM	Advanced Integration Matrix
ALS	Advanced Life Support
AMC	Autonomous Medical Care
apoE	apolipoprotein E
ARC	Ames Research Center
ASICLS	Advanced System Integration and Control for Life Support
ATLS	Advanced Trauma Life Support
BCLS	Basic Cardiac Life Support
BCPR	Bioastronautics Critical Path Roadmap
BHP	Behavioral Health and Performance
BMD	Bone Mineral Density
BPO	Bioastronautics Program Office
BR	Bioastronautics Roadmap
BRCP	Bioastronautics Roadmap Control Panel
BSMT	Bioastronautics Science Management Team
BTLS	Basic Trauma Life Support
CCP	Configuration Control Panel
Cdr.	Commander
CELSS	Closed Ecological Life Support System
CEV	Crew Explorative Vehicle
CHMO	Chief Health and Medical Officer
CMRS	CO_2 Moisture Removal System
CNS	Central Nervous System
CPCP	Critical Path Control Panel
CPR	Cardiopulmonary Resuscitation
CR	Change Request
CRL	Countermeasure Readiness Level
DCS	Decompression Sickness
DNA	Deoxyribonucleic Acid
DNR	Do Not Resuscitate
EBV	Epstein-Barr Virus
ECLS	Environmental Control and Life Support
EMU	Extravehicular Mobility Unit
Env	Environment
ESMD	Exploration Systems Mission Directorate
EVA	Extravehicular Activity
G, Gx	Unit Of Measurement For Acceleration Of Gravity; Subscripts X, Y, and Z Indicate Direction Of Force; 1G = Earth Gravity

ACRONYMS

Hab	Habitat
HACCP	Hazard Analysis and Critical Control Point
HHC	Human Health and Countermeasures
HIV	Human Immunodeficiency Virus
HSWG	Human Systems Working Group
HTLV	Human T-cell Leukemia Virus
HZE	High Mass and Energy
IAA	International Academy of Astronautics
IEEE	Institute of Electrical and Electronics Engineers, Inc.
IgE	Immunoglobulin E
I&I	Immunology and Infection
IOM	Institute of Medicine
ISRU	In-Situ Resource Utilization
ISS	International Space Station
IV	Intravenous
JSC	Johnson Space Center
K citrate	Potassium Citrate
LAC	Long Arm Centrifuge
LCVG	Liquid Cooling and Ventilation Garment
LEO	Low Earth Orbit
LET	Linear Energy Transfer
LSA	Lunar Surface Activities
MC	Medical Care
MCC	Mission Control Center
MeV	Megaelectron Volt
MRI	Magnetic Resonance Imaging
N/A	Not Applicable
NAE	National Academy of Engineering
NAS	National Academy of Science
NASA	National Aeronautics and Space Administration
NCRP	National Council on Radiation Protection
NET	No Earlier Than
NLT	No Later Than
NRA	NASA Research Announcement
NRC	National Research Council
NSBRI	National Space Biomedical Research Institute
NTSB	National Transportation and Safety Board
OAG	Operations Advisory Group
OBPR	Office Of Biological and Physical Research
OCHMO	Office of the Chief Health and Medical Officer
PCD	Patient Condition Database
PFO	Patent Foramen Ovale
PLSS	Portable Life Support System
Plt.	Pilot
psi	Pounds Per Square Inch
RAD	Radiation

ACRONYMS

RDS	Risk Data Sheet
ReMAP	Reprioritization and Maximization Committee
RH	Radiation Health
RNA	Ribonucleic Acid
rRNA	Ribosomal RNA
rpm	Revolutions per Minute
R&TQ	Research & Technology Question
SARS	Severe Acute Respiratory Syndrome
SHF	Space Human Factors
SHFE	Space Human Factors Engineering
Si	Silicon
SLS	Spacelab Life Sciences
SLSD	Space Life Sciences Directorate
SM	Sensory-Motor
SMAC	Space Maximum Allowable Concentration
SMCCB	Space Medicine Configuration Control Board
SMCL	Space Medicine Condition List
SOMD	Space Operations Mission Directorate
SP	Special Publication
SPE	Solar Particle Event
SRC	Short Radius Centrifuge
SRMS	Shuttle Remote Manipulator System
STI	Scientific and Technical Information
TBD	To Be Determined
TCCS	Trace Contaminant Control System
TGA	Trace Gas Analyzer
TMP	Transition to Medical Practice
TRL	Technology Readiness Level
TRS	Technical Report Server
U/S	Ultrasound
US/U.S.A.	United States/United States of America
UV	Ultraviolet
VPCAR	Vapor Phase Catalytic Ammonia Removal
VPU	Vegetable Production Unit

Appendix E: Glossary

GLOSSARY OF TERMS

Bioastronautics	The study of biological and medical effects of space flight on living organisms.
Bioastronautics Roadmap	The framework used to identify and assess the human systems risks associated with space flight missions and the prioritized research and technology questions required for delivering risk reduction solutions.
Cascading Risk	The relationship between interdependent risks, where one risk causes the occurrence of another.
Configuration Control	A process for maintaining the content of, in this case, the Roadmap, by a group of experts who have the authority to review and approve changes to the content of the document, and its companion Web site (http://bioastroroadmap.nasa.gov.)
Critical	Characterized by requiring careful evaluation or alignment with other tasks because of occurrence at a particularly important juncture (not meant to imply a "showstopper" connotation).
Critical Path	The path of interdependent tasks or activities in a project that determine the overall time to complete the project.
Critical Path Analysis (Method)	A project management technique that identifies the shortest possible sequence of interdependent tasks/activities in a project having the longest overall duration, determining the shortest possible path to complete the project.
Deliverables	Specific products (including knowledge that leads to medical policy and standards) identified as desirable risk reduction solutions to the research and technology questions for the human system risks.
Discipline Teams	The 15 groups of experts representing Human Health and Sytem/Performance Efficiency disciplines (bone, muscle, immunology, cardiovascular, sensory motor function, behavior and performance, radiation, environmental, nutrition, clinical capabilities, advanced life support, advanced environmental monitoring, advanced EVA, space human factors, advanced food technology).
Enabling	Providing the means, knowledge, or opportunity to make possible.
Exposure Limits	Exposure limits are based on the impact the decrement or exposure has on the capability to perform assigned tasks, and its implication for lifetime medical status. Exposure limits are used for the human health risks and refer to setting an acceptable maximum decrement or change in a physiological or behavioral parameter, as the result of exposure to space flight factors over a given length of time (e.g. life time radiation exposure).
Fitness for Duty	Fitness for duty criteria provide a measure of the crewmember's ability to perform a mission-related task or return to duty status. Examples include criteria for determining cardiovascular fitness for EVA, sensory motor functioning for vehicle egress or behavioral functioning for readiness to perform specific mission tasks.
Human System	The crewmembers, both individually and collectively, and their requirements for physical and psychological health and well-being to maximize efficiency and productivity, and the capabilities to accomplish mission goals in nominal and emergency situations.

GLOSSARY OF TERMS

Knowledge Maturation	A type of deliverable from Bioastronautics research that results from an increased understanding of a risk, its estimation, causal mechanisms, and uncertainties; resulting in, and informing, the development of medical policies and human standards.
Medical Standards	The accepted level of performance for physiological, behavioral, and performance-related functions used to set exposure-based limits for the human system, fitness-for-duty criteria, and operating bands.
Operating Bands	Operating bands represent an acceptable range of performance or functioning that is bounded at both the upper and lower limits; anything outside those limits is unacceptable. Operating bands are used in the Roadmap for the system performance and efficiency risks associated with life support and habitation systems.
Pacing Item	Critical activity that will result in the delay of the project if not completed.
Requirements	A statement, or specification, of the condition that must be met through design, procedures, or other means.
Research & Technology Questions	Research and technology questions associated with the reduction of the Roadmap risks through risk mitigation solutions (including improved efficiency, performance, and knowledge that informs crew medical policies and standards).
Risk	The conditional probability of an adverse event occurring from exposure to the space flight environment.
Risk Assessment	The scientific analysis and characterization of adverse effects on environmental hazards; it may include quantitative or qualitative descriptors, but often excludes analysis of perceived risks, risk comparisons, and analysis of effects of decisions (NRC, 1996).
Risk Factor	A predisposing condition that contributes to an adverse outcome.
Risk Management	The systematic application of management policies, procedures, and practices to the tasks of identification and assessment of human system risks for exploration missions and the development, selection, monitoring, and implementation of risk mitigation solutions for the human system for exploration missions.
Roadmap	A detailed plan to guide progress toward a goal.
Spiral Development	Gradually maturing capability or technology that repeats a particular development cycle as it matures.
Standards	Standards for the human system are represented by exposure limits, fitness for duty criteria, or operating bands. Standards for crew health and performance are established by the Chief Health and Medical Officer of NASA; mission requirements are influenced and driven by such standards.

Appendix F: References

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The Bioastronautics Critical Path Roadmap is the framework used to identify and assess the risks to crews exposed to the hazardous environments of space. It guides the implementation of research strategies to prevent or reduce those risks. Although the BCPR identifies steps that must be taken to reduce the risks to health and performance that are associated with human space flight, the BCPR is not a “critical path” analysis in the strict engineering sense. The BCPR will evolve to accommodate new information and technology development and will enable NASA to conduct a formal critical path analysis in the future. As a management tool, the BCPR provides information for making informed decisions about research priorities and resource allocation. The outcome-driven nature of the BCPR makes it amenable for assessing the focus, progress and success of the Bioastronautics research and technology program. The BCPR is also a tool for communicating program priorities and progress to the research community and NASA management.

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