HRP-47065

Human Research Program Integrated Research Plan

Human Research Program

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Revision G

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Human Research Program
Integrated Research Plan

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DOCUMENT CHANGE/ REVISION LOG

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1 INTRODUCTION

Crew health and performance are critical to successful human exploration beyond low Earth orbit. The Human Research Program (HRP) is essential to enabling extended periods of space exploration through research and technology development (R&TD) activities that are aimed to mitigate risks to human health and performance. Human spaceflight risks include physiological and performance effects from hazards such as altered gravity, radiation, hostile/closed environments, isolation and distance, as well as unique challenges in medical support, human factors, and behavioral or psychological factors. The HRP delivers human health and performance countermeasures, knowledge, technologies and tools to enable safe, reliable, and productive human space exploration. Without HRP results, National Aeronautics and Space Administration (NASA) will face unknown and unacceptable risks for mission success and post-mission crew health.

1.1 Purpose

The Integrated Research Plan (IRP) describes HRP's approach and R&TD activities intended to address the needs of human space exploration. As new knowledge is gained, the required approach to R&TD may change.

The IRP serves the following purposes for the HRP:

- Provides a means to ensure that the most significant risks to human space explorers are being adequately mitigated and/or addressed.
- Shows the relationship of R&TD activities to expected deliverables.
- Shows the interrelationships among R&TD activities that may interact to produce deliverables that affect multiple HRP Elements, Portfolios, Projects or research disciplines.
- Accommodates the uncertain outcomes of R&TD activities by including milestones that lead to potential follow-on activities.
- Shows the assignments of responsibility within the program organization and, as practical, the proposed acquisition strategy.
- Shows the intended use of research platforms such as the International Space Station (ISS), NASA Space Radiation Laboratory (NSRL), and various spaceflight analog environments including the Human Exploration Research Analog (HERA).
- Shows the budgeted and unbudgeted R&TD activities of the HRP, but does not show <u>all</u> budgeted activities, as some of these are enabling functions, such as management, facilities, and infrastructure.

1.2 Scope

The IRP documents the tasks necessary to fill the gaps associated with each risk listed and details where (e.g., the ISS or a ground analog) and who (e.g., investigators within a specific HRP organization) will accomplish the task and what is being produced (e.g., risk uncertainty

reduction, candidate health or performance standard, or countermeasure strategy). The IRP includes research that can be conducted with the resources available to the HRP, as well as research that would be performed if additional resources were available. The timescale of human space exploration is envisioned to take many decades. The IRP attempts to describe a plan of research looking forward many years into the future and illustrates the Program's research plan from early beyond Earth orbit (BEO) missions through exploration missions of extended duration. The fidelity of the IRP is quite high in the near term (2015-2018), but decreases with time. The IRP will be regularly revised and updated based on exploration mission development, achievement of key milestones, and consideration of new evidence gained.

The IRP was originally baselined as HRP-47065, Human Research Program Integrated Research Plan, in 2008. In 2010, the detailed technical content (formerly Appendix A) transitioned to the Human Research Roadmap (HRR): http://humanresearchroadmap.nasa.gov/.

1.3 Responsibility and Change Authority

This document is under Configuration Management control of the Human Research Program Control Board (HRPCB). Changes to this document will result in the issuance of change pages or a full re-issue of the document.

2 DOCUMENTS

The relationship of the HRP documents in Section 2 with the IRP is illustrated in Figure 1. A more detailed explanation of the flow depicted in Figure 1 is provided in Section 3.

2.1 Applicable Documents

The following documents of the specified revision or the latest revision if not identified, are applicable to the extent specified herein.

Document Number	Document Title
HRP-47052	Human Research Program Requirements Document
HRP-47069	Human Research Program Unique Processes, Criteria, and Guidelines (UPCG)
Various	Evidence Reports

2.2 Reference Documents

The following documents contain supplemental information to guide the user in the application of this document. These reference documents may or may not be specifically cited within the text of the document.

Document Number	Document Title
HRP-47051	Human Research Program Plan
HRP-47053	Human Research Program Science Management Plan
NASA-STD-3001,Vol. 1 and Vol. 2	Space Flight Human-System Standards, Volume 1 Crew Health and Volume 2 Human Factors, Habitability and Environmental Health
NASA/SP-2010-3407	Human Integration Design Handbook (HIDH)

2.3 Order of Precedence

All specifications, standards, exhibits, drawings or other documents that are invoked as "applicable" in this specification are incorporated as cited. All documents that are referred to within an applicable document are considered to be for guidance and information only.

In the event of a conflict between the text of this specification and an applicable document cited herein, the text of this document takes precedence.

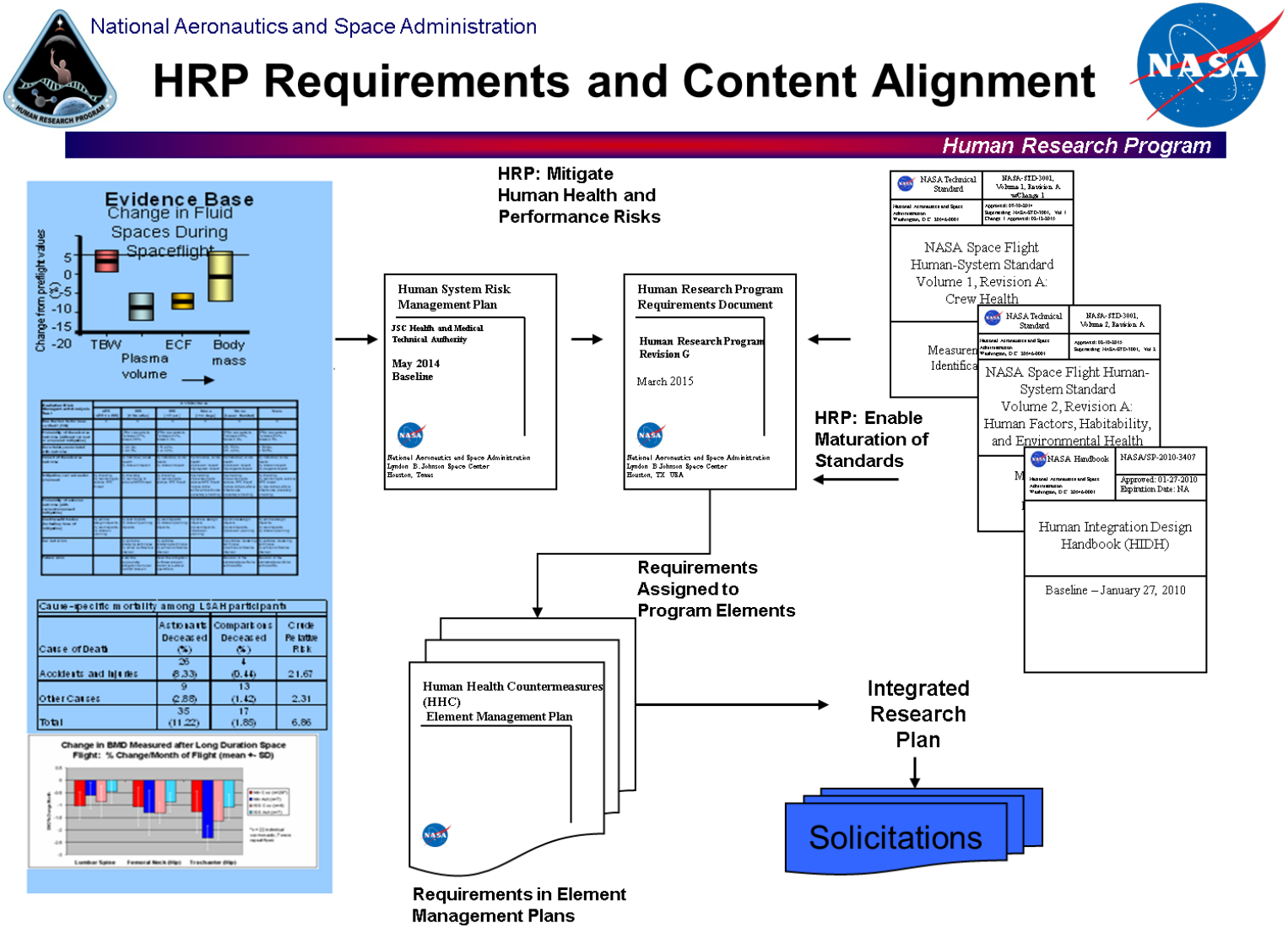


Figure 1. HRP Requirements and Content Alignment

3 CONTEXT OF THE IRP

3.1 Risk Research Portfolio

The HRP risks fall within the purview of the Office of the Chief Health and Medical Officer (OCHMO). The OCHMO established the Human Systems Risk Board (HSRB), chaired by the JSC Chief Medical Officer (CMO), to ensure a consistent, integrated process for managing human system risks that are critical to successful human exploration beyond low Earth orbit. Risks in the HRP research portfolio shall be identified by the HSRB and documented as requirements in the HRP-47052, Human Research Program Requirements Document.

3.2 Program Requirements

HRP-47052 defines, documents, and allocates the requirements to each of the HRP Program Elements: Behavioral Health and Performance (BHP), Exploration Medical Capability (ExMC), Human Health Countermeasures (HHC), International Space Station Medical Projects (ISSMP) (as an implementing Element, no risks assigned), Space Human Factors and Habitability (SHFH), and Space Radiation (SR). These HRP requirements are derived to satisfy the exploration mission requirements from Human Exploration and Operations Mission Directorate (HEOMD) and the OCHMO as found in NASA-STD-3001, Space Flight Human-System Standards, , Volume 1 Crew Health and Volume 2 Human Factors, Habitability and Environmental Health. In addition, NASA/SP-2010-3407, Human Integration Design Handbook (HIDH), was published as a compendium of human space flight history, lessons learned, and design information for a wide variety of disciplines to serve as a companion document to NASA-STD-3001, Volume 2. The HRP has two main responsibilities regarding these standards. In some cases, a NASA-STD-3001 requirement is written in generic terms to ensure its applicability to a wide range of mission environments (such as microgravity in orbit, lunar surface habitation, or transit to Mars). HRP research can serve to inform the standard, refine the requirement, and help define processes or methods (cutting edge or state of the art) to meet the requirement. Where emerging evidence or knowledge may indicate that the standards are not written in a way that captures a complete set of relevant considerations, additional research may be conducted to facilitate an update.

The requirements in the PRD are divided into three categories: requirements related to human system standards, requirements related to human health and performance risks, and requirements related to provision of enabling capabilities. Each Element, with the exception of ISSMP, incorporates its respective PRD requirements into its specific Element Management Plan. These Elements subsequently derive a research plan to address the requirements. ISSMP implements the requirements identified by the other HRP Elements for research and technology demonstration tasks that require the use of the ISS or ground analogs, as appropriate.

3.3 Human Research Program Architecture

The development of HRP content has been formulated around the architecture of:

3.3.1 Evidence

Reviews of the accumulated evidence from medical records, spaceflight operations and research findings are compiled into HRP Evidence Reports. These findings provide the basis for identifying the highest priority human risks in space exploration and are a record of the state of knowledge for each risk in the PRD. The individual risk Evidence Reports make important data accessible and available for periodic review. The HRP has published evidence-based risk reports, which are available at the following link: http://humanresearchroadmap.nasa.gov/evidence/. The documentation of evidence for each risk is in the form of a review article and broken into parts.

The National Academies of Sciences Institute of Medicine (IOM) reviews the risk reports to validate that they provide sufficient evidence that the risk is relevant to long-term space missions. The Evidence Reports will be updated at least every five years. If new evidence indicates that a risk should be retired or that a new risk should be added, the HRP will, after thorough review with the HSRB, take the appropriate action to modify the PRD and update the Evidence Reports accordingly.

3.3.2 Risks

The HRP identifies risks relevant to the Chief Health and Medical Officer (CHMO) and to the health and human performance aspects of the exploration program. The HRP utilizes the HSRB, chaired by the JSC CMO, to identify risks requiring research. The PRD allocates the requirements to quantify, mitigate, or monitor these human system risks to the appropriate Element within the HRP. The PRD, however, does not establish priority for the risks.

Each risk in the IRP is assigned a risk rating by the HSRB which is used as a tool to communicate to Agency management the seriousness of a risk to crew health and performance when applied to the mission architecture and/or mission characteristics defined for each Design Reference Mission (DRM). The risk ratings are maintained by the HSRB and serve as one of several inputs to determine the priority of each human risk, helping HRP Management make program decisions and allocate program resources. The HRP uses the HSRB forum to communicate updates to the risks resulting from HRP R&TD activities.

The IRP describes the approach and R&TD activities intended to address the needs of human space exploration. The risks-gaps-tasks-deliverables detail in the IRP is required to ensure completeness in addressing the risks. The forecasted schedule to mitigate risks is then captured in a chart called the Path to Risk Reduction (PRR). This timeline depicts significant risk milestones associated with improvements in risk ratings.

3.3.3 Gaps

For each risk requiring research, HRP identifies gaps in knowledge about the risk and the ability

to mitigate the risk. The degree of uncertainty in understanding the likelihood, consequence and/or timeframe of a particular risk as well as its criticality to the mission(s) are the major factors that drive the priority of the research gaps listed in the IRP. Gaps should represent the critical questions that need to be answered in order to significantly reduce the risk. Gaps could change over time based on research progress, current evidence, programmatic direction and mission planning scenarios. In some cases, a gap can address multiple risks.

3.3.4 Tasks

The IRP defines the tasks that will provide the deliverables required to fill the gaps. The HRP Elements identify specific research tasks that are targeted at better characterizing a risk or developing mitigation capabilities to reduce the risk to an acceptable level. A major criterion for selection of a specific task is how well the proposed research provides deliverables toward closure of the gap. A task can range from activities that define research requirements or operational needs, such as data mining and literature reviews, to a three to four year NASA Research Announcement (NRA) funded research project. Even though not specifically a R&TD activity, a data mining task can provide results which are pivotal in defining further steps in the research path, and a hardware evaluation can further the engineering approach to risk mitigation.

Tasks are solicited through an NRA, the Small Business Innovation Research (SBIR) program, NASA Request for Proposals (RFP), etc., or are directed by HRP management. The HRP's intent is that most studies are procured through competitive means, i.e., NRA, RFP, etc. In some cases, due to timeliness of data, or close interconnectedness with operations or other NASA entities, the HRP will direct that a specific study be done. Criteria for these decisions are given in HRP-47053, Human Research Program Science Management Plan (). The current or planned procurement method for each task in this research plan is identified. Identification of any investigation as a directed study within the IRP does not signify a commitment on the part of the HRP to implement that study as a directed study without further consideration by the Chief Scientist as specified in HRP-47053.

It is the HRP's policy that all investigations sponsored by the program will undergo independent scientific merit review. This includes proposals submitted in response to NRAs, all directed study proposals, and all unsolicited proposals.

3.3.5 Deliverables

Each task or progression of tasks is designed to ultimately culminate in deliverables or products. Two organizations are the primary customers for HRP deliverables: OCHMO and HEOMD.

Common deliverables include recommended standards (e.g., Permissible Exposure Limit), requirements (e.g., flight rule), risk characterization, countermeasures, clinical practice guidelines, and technology. Specifications for some deliverables are agreed upon with customers of HRP products through the use of Customer-Supplier Agreements. After deliverables are provided, the R&TD results are assessed for applicable updates to the evidence base as it impacts risks, gaps and tasks in order to achieve risk reduction goals as laid out in the PRR.

3.4 Research Platforms

The HRP utilizes various research platforms and data sources to address gaps in knowledge. Data mining involves gathering and analyzing data from historical spaceflights via the Lifetime Surveillance of Astronaut Health (LSAH), spaceflight operational data (e.g., landing performance and simulator performance data), and other sources to identify possible correlation with physiologic or psychological function, and relevant data from ground studies (NASA-sponsored and otherwise).

The HRP utilizes the ISS and other flight platforms as they become operational to conduct research requiring the unique environment of space. The spaceflight data primarily identify and/or quantify physiological and behavioral changes to the human system occurring in the microgravity environment. The ISS is utilized to validate potential countermeasures, as an analog for long-duration exploration missions, and to gather data to define space normal as given in Section 3.5.

The use of the ISS platform, in several cases, is critical to obtaining the required knowledge to build products supporting longer, more challenging missions. The Shuttle retirement in 2011, the uncertainty in replacement transport vehicles to ISS, and the planned retirement of the ISS in 2024 levy significant constraints on available flight resources. However, since not all research that requires the ISS can be accomplished by 2024, the HRP will continue to plan use of the ISS as a viable research platform should the vehicle retirement be extended beyond the 2024 timeframe or an alternate analog platform can be found. Where possible, the HRP will utilize ground-based analog environments to perform the research required to fill gaps in knowledge, preserving the limited flight resources for only those that cannot be addressed elsewhere. HRP utilization of the ISS is managed by the ISSMP Element.

There are several analog environments utilized by the HRP, some owned and operated by HRP, some by NASA, and others operated by other agencies. Each analog environment is assessed for its characteristics that mimic portions of the flight environment. No ground-based analog can serve to simulate the flight environment completely; thus each analog to be used is selected based on its important flight-like characteristics specific to the task objectives. The use of several analogs may be required to fill a gap. Throughout the IRP, tasks requiring the use of specific analogs are identified. The HRP Flight Analogs Project (FAP), within the ISSMP Element, coordinates utilization of some ground-based research analogs to complement space research. HRP utilization of the NSRL is managed by the SR Element.

3.5 Functional Definition of Space Normal

Space normal is defined for this document as the normal human response to prolonged spaceflight. As NASA prepares to send crewmembers on extended exploration missions, questions arise regarding the impacts of the spacecraft and surface exploration environment on the health, safety, and performance of the explorers. The normal human response to prolonged microgravity exposure during (and after) orbital spaceflight missions has received considerable research attention, but little is known about the human physiological responses to prolonged fractional gravity exposure. It would be useful to know ahead of time whether any of the effects

could be severe enough to cause functionally significant decrements in crew health, safety, or performance during these missions, so that appropriate countermeasures could be provided from the outset.

All organ systems are affected by the environmental factors associated with spaceflight, although the time frame and degree of negative impact on astronaut health and performance is highly variable. The spectrum of consequences to human health and performance ranges from catastrophic through steady loss or decrement, to short-term transitional adjustment, to benign with no meaningful impact. Currently, the HRP approach for each physiological condition or organ system of concern is to:

1. Document the acclimated state.
2. Recommend revisions to crew health standards if that state is medically unacceptable.
3. If unacceptable, then determine physiological mechanisms of action.
4. Develop countermeasures as appropriate.

The acclimated state is understood to represent space normal, the newly adapted normal baseline physiological state. A rigorous definition of space normal must consider the presence or absence of pre-existing clinical conditions and legacy countermeasures, as well as variability in incident SR, ambient atmospheric pressure, temperature and composition; acoustics; lighting; etc., in addition to the absence of apparent gravity. In particular, all experiments currently defining space normal on ISS are conducted in the presence of an exercise prescription that has varied from mission to mission and astronaut to astronaut over the first decade of ISS operations.

With an accepted definition of space normal, HRP would be in a position to recommend whether or not to allow acclimation to spaceflight conditions, and if so, to what degree: acclimation followed by treatment just prior to or after Earth return; acclimation accompanied by in-flight monitoring and countermeasures implementation at a predetermined degree of decrement; or no acclimation permitted whatsoever.

3.6 Hardware and Countermeasure Development Cycles

Many HRP deliverables contribute to hardware development. NASA hardware development proceeds through several stages, with reviews occurring between the stages. The exploration program goes through these stages as it designs the next crew capsule, a lunar lander, and the next generation space suit. Common reviews seen in the HRP documentation are as follows:

- System Requirements Review (SRR): At the beginning of the project, establishes what the system will and will not do.
- Preliminary Design Review (PDR): At 10% design completion, is primarily to critique the architecture of the design and critical decisions made in the design.
- Critical Design Review (CDR): At 90% design completion, is primarily to make a last set of changes before the design is finalized.

To make sure that all the organizations within NASA and its associated contractors are working from the same set of plans, NASA uses a rigorous “configuration management” system to obtain,

review and implement changes to key documents. A change is initiated by a formal document called a Change Request (CR). A CR often solicits input from many stakeholders. That input is often provided in the form of a Review Item Discrepancy (RID). A RID is essentially a request to change part of a document and includes the rationale. The owner of the document decides whether or not to make the change. The HRP often provides RIDs to CRs concerning exploration program documents. This is the NASA process that allows HRP results to change NASA's plans for exploration vehicles.

Design solutions and technology typically must be defined to a Technology Readiness Level (TRL) 6 by the PDR. TRLs are defined in Appendix B.

The HRP nominally begins a countermeasure development at Countermeasure Readiness Level-4 (CRL-4) and develops the selected countermeasure to CRL-7 or -8. At this point, the HRP transfers the countermeasure to the implementing organization for incorporation. For some Elements, Space Radiation for example, countermeasure development must begin at much lower CRLs and are thus developed to CRL-6 prior to transition. CRLs are defined in Appendix B.

4 RESEARCH APPROACH

The IRP describes a plan of research that addresses both human physiology, human performance and the interconnected system of the human and spacecraft in a highly integrated manner. It is often not possible to address the risks simply as stand-alone units. The knowledge or mitigation gaps often appear in multiple risks. Many of the specific research tasks address multiple gaps across risks.

In the following sections, the PRD risks are listed by HRP Element. Sections 4.1 through 4.5 provide a high-level view of the research approach to the risks. The HRP Elements are arranged in the following order:

1. Behavioral Health and Performance
2. Exploration Medical Capability
3. Human Health Countermeasures
4. Space Human Factors and Habitability
5. Space Radiation

Detailed information about gaps and tasks for each risk is located in the HRR: http://humanresearchroadmap.nasa.gov/.

The interactions between the risks, gaps, and tasks are not readily shown in a printed book. In the HRR database, the user will be able to search for such items as gaps associated with a risk, the tasks associated with a given gap, the cross-integration of a task across multiple gaps or risks, and deliverables associated with a gap or task. The research rationale statement for each risk is included in the PRD, Table C-2.

4.1 BHP

All BHP risks are highly interrelated. Occurrence or mitigation of a risk can be a contributing factor affecting another.

4.1.1 Risk of Adverse Cognitive or Behavioral Conditions and Psychiatric Disorders (Short Title: BMed)

Given the isolated, extreme and confined nature and extended duration of future space exploration missions, there is a possibility that

a) adverse behavioral and cognitive conditions will occur; and
b) behavioral and cognitive disorders could develop should adverse behavioral and cognitive conditions be undetected and unmitigated.

We do not have a full understanding of the detrimental impact that spaceflight missions of one-year and longer will have on behavioral health and performance. Evidence from ground-based analogs, suggests there is a significant impact on the performance and behavioral health of individuals. Early detection of risk factors such as increased stress and decriments in cognition due to a variety of spaceflight stressors (e.g., high workload, circadian desynchrony, elevated carbon dioxide (CO_2), radiation, diet and nutrition, separation from family, limited volume, confinement and isolation) during spaceflight is important to deter development of cognitive and behavioral degradations or a psychiatric condition that could seriously harm and negatively affect the individual or the crew, and pose serious consequences for accomplishing mission objectives or jeopardizing the mission altogether. Toward this end, BHP is developing methods for monitoring cognitive and behavioral health during long duration exploration missions, and adapting and refining various tools and technologies for use in the spaceflight environment. These measures and tools will be used to monitor, detect, and treat early risk factors. BHP will utilize analogs to test, further refine, and validate these measures for exploration missions. BHP also develops countermeasures for maintaining and enhancing BHP and treating cognitive and behavioral problems during and after long-duration isolated, confined, and highly autonomous missions.

4.1.2 Risk of Performance and Behavioral Health Decrements Due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team (Short Title: Team)

While relatively few empirical studies have been conducted regarding the impact of interpersonal and intrapersonal factors on spaceflight performance, it is possible that team level issues could jeopardize long duration exploration missions. Reports from Mir reveal that several missions may have been terminated earlier than planned due to friction between crewmembers, and some veteran NASA astronauts have reported crew conflict during previous space travels. Understanding the potential negative impacts of interpersonal and intrapersonal issues from spaceflight and relevant, high fidelity analog environments is important for identifying countermeasures to aid crewmembers (ground and space) during exploration missions (e.g., asteroid rendezvous and Mars) where operations will require more autonomy from the ground.

BHP has conducted, and will continue to conduct, literature reviews and interviews of crew and operations personnel to determine the most likely and most serious threats to crew cohesion, crew performance, and crew-ground interaction that might be expected for long-duration exploration missions. These interviews are then used to inform follow-on studies with the goal of identifying the critical drivers of team functioning, formulating objective measures for monitoring crew cohesion, and developing approaches to enhance current training as well as building upon the current highly successful in-flight support services and countermeasures. These measures and countermeasures are then tested for feasibility and acceptability in appropriate analog environments. These tests are followed, where appropriate, by studies of ISS crews examing cohesion/performance while implementing these measures and countermeasures.

As crews begin operations for long-duration missions beyond low Earth orbit, they will need to exercise increasing command and control of their daily activities. The distance for Mars missions will result in the loss of capability for real-time communication and coordination with Mission Control. Likewise, the crew will have to augment and adapt their planning and schedules based on real time changes in the mission and environment. The extreme distance and the duration of the planned Mars mission are at the boundaries of our current knowledge of how teams function. A better understanding of how to approach and address autonomous operations and its impact on crew dynamics and performance will help inform standards and countermeasures for use during long-duration exploration missions.

4.1.3 Risk of Performance Decrements and Adverse Health Outcomes Resulting From Sleep Loss, Circadian Desynchronization, and Work Overload (Short Title: Sleep)

Objective and subjective evidence indicates that during ISS and Shuttle missions, sleep is reduced and circadian rhythms are misaligned (Barger et al., 2014). While a terrestrial baseline of astronaut sleep has not yet been established, the average nightly sleep duration of crewmembers for both short and long duration missions is around six hours, with crewmembers showing a significant increase in sleep duration once they return to earth, indicating a sleep debt may have accrued on orbit.

Ground evidence clearly demonstrates that performance impairments can occur when sleep is attained in quantities similar to that attained by astronauts in flight. While a correlation between sleep quantity and performance during spaceflight has not yet been established, a BHP investigation is seeking to characterize the relationship between sleep quantity and vigilance and attention during spaceflight. Future data mining efforts may also yield insight into the relationship between sleep duration and circadian phase, with other outcomes (e.g., immune health, operational performance).

BHP research aims to further characterize and quantify this risk by implementing studies on ISS using standardized measures to evaluate performance relative to fatigue. Planned data mining efforts seek to further investigate contributors to sleep loss, fatigue, circadian desynchronization, and work overload, by evaluating environmental factors, individual vulnerabilities, and mission timelines. Ground assessments incorporating head-down tilt, varying CO_2 levels and other factors can allow for systematic assessment of additional stressors. The role of sleep and

circadian phase in other outcomes (i.e., BMed and Team studies) will also be further evaluated through analog research.

Such investigations help to inform the optimal countermeasure strategy for mitigating the health and performance effects of sleep loss and related issues in flight. As an example, studies indicate that properly timed light exposure can help maintain circadian alignment, and facilitate schedule shifting, performance and alertness. Current efforts aim to determine the operational protocols and technical requirements for lighting systems on the ISS, as well as future exploration vehicles. Other countermeasures that are currently being investigated include recommendations around sleep education and training; sleep-wake models of performance that can inform real time scheduling decisions as well as optimal ways to individualize countermeasure regimens; and investigations that seek to provide educational materials related to sleep-wake medications. The effectiveness of other potentially relevant countermeasure strategies, such as stress management, diet, and exercise, may also be assessed.

4.2 ExMC

4.2.1 Risk of Unacceptable Health and Mission Outcomes due to Limitations of In-flight Medical Capabilities (Short Title: ExMC)

The primary objective of the ExMC Element is to minimize or reduce the risk of unacceptable health and mission outcomes due to limitations of in-flight medical capabilities on human exploration missions. Medical conditions of varying complexity are expected to occur during these long-duration missions outside of low Earth orbit (LEO) to destinations such as the Moon, asteroids, or Mars. Several factors necessitate increased medical capabilities on such missions. Mission lengths for these missions may range from several weeks to several years, and the number of medical events is expected to increase with mission length. Additionally, mission architecture and orbital mechanics may preclude timely evacuation during phases of exploration missions. Further, consultation with medical experts on Earth may be hindered by communication delay or blackout periods. Thus, medical care, including emergency treatment and psychological support, will be rendered by the crew in an autonomous fashion during certain periods.

Genuine difficulties in providing medical care on exploration missions include, but are not limited to, the following:

a) resource constraints resulting from the boundaries of the mission design and architecture (volume, mass, power) dictating that only the most critical medical equipment be stored onboard the space vehicles and delivered to the space habitats;
b) the potential for delivery of medical care by a non-physician for missions outside of LEO less than 210 days in length;
c) limited pre-flight crew training time necessitating tailoring of training to the medical knowledge, techniques and procedures that address the medical situations most likely to occur;
d) the need for crewmembers to be prepared to respond to emergency medical conditions without real-time support from Earth; and

e) the possibility of encountering unpredicted common illnesses, as well as, ailments that may be unique to the space environment.

The Element seeks to ensure crew health and secure mission success on exploration missions through a) thorough pre-flight health status assessment, including new technological approaches, and b) development of a systematic approach to a more comprehensive autonomous health care system in space.

ExMC addresses this broad risk using the framework outlined within the HRP PRD and through decomposition and analysis of the requirements allocated to ExMC.

A first step in mitigation of human health and performance risks is the establishment of human spaceflight health standards. These standards are designed to address acceptable levels of human health and performance risks for exploration missions of varying complexity and duration. The NASA OCHMO has established an initial set of standards that serves to guide the HRP in the expansion of its evidence base regarding human spaceflight health and performance risks. ExMC sponsors R&TD which may require modification or development of OCHMO maintained standards. Additionally, NASA exploration missions may require new knowledge and/or new technology development either to support current standards or to modify standards for mission success. In either situation, the ExMC Element Scientist, working with the Medical Operations Lead for standards, will determine gaps in knowledge in the current standards and identify tasks to close those gaps.

Incidence rates and outcomes for relevant medical conditions have large uncertainties associated with them due to limited available operations and research data. The Exploration Medical Condition List was created and is analyzed regularly to determine gaps in knowledge about medical conditions' incidence rates and outcomes in spaceflight. Tasks are then assigned to further study, model, and use analog population data to better quantify the medical conditions.

In addition, the Exploration Medical Condition List is analyzed for the capabilities required to monitor and treat the conditions based on the DRM defined in the HRP PRD. An analysis is performed to determine where gaps exist in current medical system capabilities and where efficiencies could be realized in the future. Based on when a capability or technology is needed, a technology watch is implemented or a capability development project is initiated.

4.2.2 Risk of Renal Stone Formation (Short Title: Renal)

Research in Nutrition Discipline and in anti-resorptive pharmaceutical agents is evaluating modifications to bone turnover – an established risk factor for renal stone formation. Ultrasound artifact diagnostics are being explored to improve early detection of stones in the renal pelvis. The potential for moving renal stones through application of ultrasound is being developed as an approach to providing clinical mitigation of renal stone risks.

4.2.3 Risk of Ineffective or Toxic Medications Due to Long Term Storage (Short Title: Stability)

The risks associated with use of expired or degraded medication are well-established. A special area of concern with respect to exploration missions is the safety and efficacy of medications throughout extended missions. ExMC seeks to understand how medications are currently being used in spaceflight through retrospective review of medication use and developing a dose tracker application. Direct assessment of medication stability will be done through a stability study including assessments of effects from room temperature, refrigerated, and radiation environments. Additionally, an in-flight medication analysis device is being developed which could provide point of use assessments for medication.

4.3 HHC

4.3.1 Risk of Inadequate Nutrition (Short Title: Nutrition)

As mission duration increases, the risk of nutrient deficiencies becomes greater. Nutrient requirements, food system requirements, and the need to preserve the nutrient content in food are all important issues that need to be well characterized before we can safely embark on exploration missions. Also, nutrition risks will increase as the frequency and duration of extravehicular activity (EVA) increases on surface missions. Nutritional countermeasures can influence all systems, and conversely, countermeasures for other systems may impact nutritional status and requirements.

Space normal must be defined for this risk; a comprehensive nutrition study (Nutrition Supplemental Medical Objective [SMO]) is ongoing. Once space normal is defined, the data will be presented to the HSRB for determination of the need for countermeasure to be developed. In addition, several studies are ongoing to determine effects of optimized dietary intake on bone and cardiovascular health and the effects of oxidative damage on nutrition and other systems.

4.3.2 Risk of Early Onset Osteoporosis Due to Spaceflight (Short Title: Osteo)

The Fracture and Osteo risks are interrelated by sharing the physiological outcome of fracture. However the type of fracture, the causality of fracture, the timing of the fracture incidence and the mitigation approach and resources for the two fracture risks may be different. The definition of skeletal changes due to spaceflight will inform both risks. The combined research risk approaches are presented below.

To address these risks, it is currently possible to

1) track the effect size of long duration missions by changes in bone mineral density, in biomarkers of bone turnover and in bone structure for the hip and spine,
2) project if bone losses will occur during a Mars visit, and
3) use such information to estimate the risk of fracture upon return to Earth after a Mars mission.

However, these capabilities are not part of any requirements documents for Lunar or Mars missions. Currently there are indications that, after 6-month missions, bone quality, and thus bone strength, does not recover as quickly as bone mineral density. This may influence a skeletal health after return to Earth (contributors to osteoporosis and fracture risk) related to this discordant recovery dynamic. This information is required for assessing long-term health risks to returning crew.

In spite of the long history of collecting bone relevant data, there are still gaps in knowledge. Bone atrophy during spaceflight is well recognized and may require mitigation to prevent fractures, but the time course of in-flight bone changes has not been determined. Furthermore, the time course of post-flight recovery and the individual susceptibilities to multiple risk factors have not been defined well enough to assess the probability of fractures. Hence, NRAs are utilized to solicit and select proposals to gather these space adaptation data. In addition, work is ongoing with the Space and Clinical Operations Division to obtain bone surveillance data. To this aim, the current bone standards based upon diagnostic guidelines for age-related osteoporosis are not acceptable for assessing skeletal integrity in the younger-aged astronaut following prolonged spaceflight exposure. Therefore, per the recommendation of clinical policy-makers in the field of osteoporosis and bone mineral density, an evidence base from population studies with fracture outcome, is being assembled, and analyzed to generate a modified set of operating bands for skeletal integrity in astronauts. Finally, to address early-onset osteoporosis, methods to monitor the combined skeletal effects of spaceflight with effects of aging are required to predict fractures and to determine an intervention threshold to prevent premature, age-related fractures in the astronaut. Overall, the long-term goals of the HHC Element are to develop and deliver countermeasures for long-term missions and to establish the efficacy of countermeasures according to the newly formulated standards for skeletal integrity.

The risk for fracture, however, requires integrating a biomechanical component. The Factor of Risk (FOR) for fracture is defined as the ratio between the applied load vector to bone and the bone fracture load (which capture both magnitude and direction of load). Thus, the increased fracture risk induced by spaceflight is inferred collectively from the accelerated loss of bone mass, to the changes in hip bone structure, and to the probability that bones will be overloaded while working and performing tasks in an encumbered, atypical, unknown risk environment. The most critical work needed for this risk requires assessing in-flight changes in bone mass and structure over the course of ISS missions. This increased understanding of spaceflight effects on bone (particularly of hip, wrist and spine) in LEO are limiting but can help inform the probabilistic assessment of fracture risk for future planetary mission, e.g., Mars. Those data will provide a basis for evaluating whether the expected loads/torques to bone during human performance on a mission will exceed the failure load of bone (i.e., fracture load). This knowledge can be used to direct mission operations planning.

Notably, the Risk of Bone Fracture deals with fractures occurring during a mission up until landing on Earth. The incidence of fractures occurring after return to Earth, in contrast, will fall under the surveillance for The Risk of Early Onset Osteoporosis Due to Spaceflight. The modalities and medical tests used to assess changes to bone mineral density and bone quality are

applicable to both the Fracture and Osteo risks. The independent gaps in the Risk of Bone Fracture address fracture healing and estimating fracture risk during a mission.

4.3.3 Risk of Cardiac Rhythm Problems (Short Title: Arrhrythmia)

There have been several reports of cardiac arrhythmias during long-duration spaceflight including one Russian Cosmonaut who was deorbited due to a serious arrhythmia. Some have been related to cardiovascular disease, but it is unclear whether this was due to pre-existing conditions or to the effects of spaceflight. It is believed that advanced screening for coronary disease has greatly mitigated this risk. Other heart rhythm problems, such as atrial fibrillation, can develop over time, necessitating periodic screening of crewmembers' heart rhythms. Beyond these terrestrial heart risks, exposure to certain elements of space flight, such as radiation, stress, and altered diet and exercise may potentiate both rhythm disturbances and vascular disease, not only during flight, but for years post-flight.

Space normal must first be defined for this risk. Once defined, the data will be presented to the HSRB to determine if countermeasures are needed. Preliminary results from a comprehensive study designed to investigate the incidence of arrhythmia suggest that risk of inflight arrhythmia may not be increased during space flight, but did not investigate long-term cardiovascular health outcomes after landing.

4.3.4 Risk of Injury and Compromised Performance Due to EVA Operations (Short Title: EVA)

Performance of spaceflight EVA consists of placing a human in a micro-environment which must provide all the life support, nutrition, hydration, waste, and consumables management functions of an actual space vehicle, while allowing crewmembers to perform as closely as possible to a 1-g shirt-sleeved environment. Influences from the combination of EVA or EVA training operational factors (task, equipment and resources design, altered gravity environment), suit design (suit fit, pressure, mass, center of gravity, joint mobility) and crew characteristics (physical preparation, state of fatigue) can place physiological and functional demands on the crew that lead to injury, compromised physiological performance and incomplete mission objectives. Past EVA systems have already presented significant limitations and challenges for suited crewmembers, including the fact that not all crewmembers were capable of performing EVA. This was not required in the context of their role during Shuttle and ISS missions. However, during the exploration program, all crewmembers will need to perform at a high level of competence in the suit. Therefore, it is critical to understand the relationships among EVA suit parameters, subject characteristics, and health and performance.

Mitigation of this risk will require research to characterize injury risk human performance across a range of EVA suits using representative tasks and gravity environments simulated in different analog facilities. This research should inform human centered spaceflight EVA standards, injury surveillance needs and injury mitigation countermeasure. Through this work, we expect these results to lead to the creation of EVA systems that optimize human health and performance across the spectrum of anticipated exploration operational concepts.

4.3.5 Risk of Decompression Sickness (Short Title: DCS)

Future space exploration missions will have important differences in the variables that affect decompression sickness (DCS) compared to the Shuttle or ISS programs. There is a substantial gap in the existing data, operational experience, and risk prediction tools that must be addressed to quantify and control the risks associated with EVAs. These differences include changes in: cabin pressures, oxygen concentrations, EVA metabolic profiles, ground reaction force doses, lower body musculoskeletal work, gravity levels, suit pressures, suit breathing gas mixtures and EVA durations and frequencies. The occurrence of DCS on lunar or other exploration missions will potentially have severe impacts to crew health and mission success. Return to Earth may take days to months vs. 24 hours or less from ISS. Losing one or more crew members to DCS (even for a few days) will have a profound effect on EVA frequency and therefore completion of exploration mission objectives.

Due to the remoteness and potential for catastrophic individual health and mission impact, and unavailability of standard treatment modalities, preventative measures should be the approach predominantly used by NASA for mitigating DCS risk. Consequently, there is a need to perform extensive and comprehensive human research studies to evaluate the risk of DCS based on the anticipated operational mission scenarios. Current non-validated modeling is inadequate to form the basis for operational procedures.

4.3.6 Risk of Adverse Health Event Due to Altered Immune Response (Short Title: Immune)

Recently, dysregulation of certain aspects of adaptive immunity has been found to be an in-flight phenomenon which persists for the duration of a 6-month orbital spaceflight. Attributes include altered leukocyte distribution, diminished T cell function, dysregulated cytokine profiles. This immune dysregulation directly leads to the chronic reactivation of latent herpesviruses in Astronauts. Further, it appears that certain adverse medical events potentially related to immune dysregulation occur in some crewmembers. These events include atypical allergic symptoms and hypersensitivity reactions, and various infectious processes. While these phenomenon are not resulting in significant operational concerns during ISS missions, as orbital baseline data they suggest crew clinical risk may be elevated during deep-space exploration missions. In synergy with increased radiation, stress and perceived risk, circadian misalignment and limited care/return options, immune dysregulation is likely to worsen during such missions. Currently, Tasks are being planned which will characterized previously uninvestigated aspects of immunity during spaceflight. Following complete characterization, NASA may initiate an assessment of clinical risk for exploration missions, development of a monitoring strategy, and discussions about the appropriateness and nature of immune countermeasures. In parallel, analog validation activities are ongoing, including Antarctica winterover, that would provide the most appropriate ground analog to aid characterization of the flight phenomenon, and provide a terrestrial opportunity for countermeasures evaluation.

4.3.7 Concern of Intervertebral Disc Damage upon and immediately after re-exposure to Gravity (Short Title: IVD)

Evidence from medical operations indicates that astronauts have a higher incidence of intervertebral disc (IVD) damage than the general population. On-going surveillance will evaluate the incidence of intervertebral disc damage. Current studies are characterizing the effects of spaceflight on the vertebral unit (vertebral bodies/IVD/musculature). Once completed, the findings could be used to guide the design of re-entry and post-flight protocols, as well as future re-entry spacecraft, as appropriate.

4.3.8 Concern of Clinically Relevant Unpredicted Effects of Medication (Short Title: PK/PD)

This concern is based on knowledge of demonstrated spaceflight effects on human physiology that would logically alter the pharmacology of administered medications. Because of the physiological changes that occur during spaceflight, it seems likely that pharmacokinetics (PK) (how the body handles administered medication) and possibly pharmacodynamics (PD) (how administered medication affects the body) could be different during spaceflight. Knowledge of in-flight medication use, efficacy, and side effects is expected to provide preliminary information on these points. Several data mining tasks are in progress to collect this information. Additional studies, possibly during spaceflight, may be required to fully address the issues.

4.3.9 Risk of Impaired Control of Spacecraft/Associated Systems and Decreased Mobility Due to Vestibular/Sensorimotor Alterations Associated with Spaceflight (Short Title: Sensorimotor)

Evidence from 30 years of Shuttle flight indicates that research on impaired control of spacecraft due to sensorimotor disturbance is not a high priority for Shuttle or ISS. However, since Mars operational scenarios are still to be determined (TBD), it is agreed that the ISS should be utilized to gather the data required to define the research that might be needed to enable future Mars mission operations. It first must be determined what relevant spaceflight data exist and if they are accessible. If so, they must be analyzed; if not, the data must be collected. In addition, performance related to neurosensory dysfunction should be used to determine the need for further research and countermeasure development.

Space normal must first be defined for this risk; data mining tasks are ongoing. Once the definition is in place, the data will be presented to the HSRB, and a determination made on whether countermeasures need to be developed. In addition, the NRA solicitation process was utilized to obtain proposals to determine any manual and visual control deficits.

4.3.10 Risk of Impaired Performance due to Reduced Muscle Mass, Strength and Endurance (Short Title: Muscle) and Risk of Reduced Physical Performance Capabilities due to Reduced Aerobic Capacity (Short Title: Aerobic)

The Risk of Impaired Performance due to Reduced Muscle Mass, Strength and Endurance and Risk of Reduced Physical Performance Capabilities due to Reduced Aerobic Capacity are

related. Occurrence or mitigation of one risk can be a contributing factor affecting the other. Exercise is the mitigation strategy for both risks and an efficient exercise program could likely mitigate both risks simulatenously.

Loss of aerobic fitness has been characterized during spaceflight with an average loss of 17% within the first 2 weeks that remains depressed throughout flight and for the first 30 days post-flight. Individaul data clearly demonstate this is not an inevitable consequence of spaceflight and that it is possible to change (increase or decrease) aerobic fitness during flight using exercise.

Loss of muscle size and function (strength, endurance, coordination, etc) are normal physiologic responses to unloading induced disuse, therefore decrements observed during and following spaceflight indicate normal homeostatic processes. Using resistance exercise of sufficient duration and intensity it is likely, though not yet proven definte, to be a fully effective countermeasure. Therefore, some of the primary research emphases include:

- development of optimal exercise prescriptions using ISS exercise equipment to prove the efficacy of exercise countermeasures alone
- determination of whether adjuncts are required for either nominal or off nominal exercise conditions
- understanding the time course of muscle decrement in order to extroplate ISS results to increasingly longer missions
- a more thorough understanding of the relationshiop among key muscle and aerobic parameters and performance of mission tasks
- development of next generation exercise equipment to provide for a sufficient exercise intensity and documented efficacy while being more resource efficient (size, mass, power, etc.)

4.3.11 Risk of Orthostatic Intolerance during Re-Exposure to Gravity (Short Title: OI)

Twenty percent of Shuttle crewmembers and up to 66% of returning ISS crewmembers suffer hypotension and presyncope or syncope during 10 minutes of upright tilt on landing day. The current suite of countermeasures, which include fluid loading and compression garments, partially control orthostatic intolerance (OI) during re-entry to Earth’s gravity. Furthermore, the presence of ground medical personnel upon landing, who can administer intravenous fluids and other medical support, can further mitigate this risk. While crewmember orthostatic responses are well known after six-month missions when they return to Earth’s gravity, the response to the 3/8 g environment on the Martian surface is not known. The lack of a ground support team on the Martian surface will further increase this risk. Space normal has been defined for this risk. Current research efforts include investigations to determine the efficacy of new generation compression garments and improved fluid loading, which will be critical for future exploration class spaceflight.

4.3.12 Risk of Spaceflight-Induced Intracranial Hypertension/Vision Alterations (Short Title: VIIP)

Astronauts on long duration ISS missions have experienced elevated intracranial pressure (ICP), ophthalmic anatomical changes and visual performance decrements of varying degrees. Presently these symptoms have manifested themselves as changes in eye structure such as optic disc edema, globe flattening, choroidal folds, cotton wool spots, increased nerve fiber layer and/or decreased near vision along with post-mission spinal opening pressures ranging from 18-28.5 cm $H_2$0 for symptomatic astronauts. Present pre-, in-, and post-flight data indicate that after approximately 6 months of space flight, 21 of 30 US crewmembers that have been evaluated have shown symptoms of the Visual Impairment/Intracranial Pressure (VIIP) syndrome. The cases are graded based on the criteria in the VIIP Clinical Practice Guidelines (CPGs). The symptoms considered are refractive change, presences of globe flattening, choroidal folds, cotton wool spots and/or increased retinal nerve fiber layer along with the severity of optic disc edema (using the Frisen Scale). Incidence to date has shown a rate of 70% of those tested with a 20% rate for the most severe clinically significant classes (3 and 4).

A summit was conducted in February 2011 with national and international experts in ophthalmology, neuro-ophthalmology, neurosurgery, neurophysiology, and cardiology. Participants provided suggestions for pre-, in-, and post-flight operations as well as research areas with respect to detection, monitoring, treatment, imaging, susceptibility, computer modeling, and/or use of analogs. Results from the summit reinforced the existence of multiple contributing factors with no clear cause identified. Leading hypotheses are currently being investigated with a series of ground and flight studies. Ultimately, the goal of both Space Medicine Operations and the Human Research Program is a set of preventative and treatment countermeasures for the syndrome. The VIIP Research and Clinical Advisory Panel (RCAP), comprised of recognized experts in the fields relevant to VIIP, monitors progress and provides guidance to NASA.

4.3.13 Infrastructure

The HHC Element also owns gaps related to Element infrastructure that are related to multiple risks. These gaps capture development of knowledge and technologies, including, but not limited to, spaceflight analog development, artificial gravity and animal studies that are related to integrated physiological systems. These gaps are listed as HHC1-3 and HHC5 in the HRR.

4.4 SHFH

4.4.1 Risk of Adverse Health Effects due to Host-Microorganism Interactions (Short Title: Microhost)

While current preventative measures limit the presence of many of the medically significant microorganisms during a mission, infections cannot be completely eradicated. Evidence indicates that certain characteristics of microorganisms are altered when microbes are cultured in spaceflight. These alterations include changes in virulence (disease-causing potential). As a result of this evidence, the HRP plans to compare microbial diversity, microbial characteristics,

and specific host-microorganism interactions between spaceflight and ground-based conditions. This comparison, in combination with evidence from investigations of potential changes in crew susceptibility, will be used to determine the risk of microbiologically-induced adverse health effects during a spaceflight mission. Using this microbial risk assessment, the HRP will determine if current operational and engineering controls used to mitigate these microbiological risks during human exploration of space will be adequate or whether additional countermeasures should be developed.

4.4.2 Risk of Adverse Health & Performance Effects of Celestial Dust Exposure (Short Title: Dust)

The impact of exposure to dust from extraterrestrial sources (celestial dusts) can range from being a minor nuisance to having major health implications. These dusts can have a high content of respirable size particles, have large surface areas that are chemically reactive, and "nano-particles" of highly reactive elements such as iron (Fe^0). These unusual properties may cause the respirable dusts to be at least moderately toxic to the respiratory system and the larger grains to be abrasive to the skin and eyes. NASA needs to understand the implications of exposure to these dusts so vehicle and habitat designs will include features that maintain concentrations of airborne dust within safe limits and operations minimize the risk of abrasion to the skin and eyes.

Research will evaluate and characterize factors that contribute to toxicity of the celestial dust, and develop standards for future missions where the crew is exposed. Studies may include determination of size distributions, shape characteristics, and chemical composition of lunar particulates.

In vivo studies evaluating inhalation toxicity and intratracheal instillation (ITI) are also common in understanding the impact of dust inhalation.

Previous studies have characterized the toxicity of long-duration exposure to lunar dust, enabling the establishment of a Permissible Exposure Limit; however, other celestial dusts have different characteristics. The threat from surface dust on an asteroid will depend on the size of the asteroid and non-gravitational properties that allow the dust to adhere to the asteroid surface. Martian dust is likely to be reactive (Viking evidence) and of a size to be easily respirable. The respirability is a consequence of global and local dust storms that cause collisional breaking of dust grains into smaller grains. Crews could be exposed to dust brought into the habitat on EVA suits and on hardware.

Volatiles are unlikely to be a problem during exploration of rocky asteroids; however, carbonaceous asteroids, which comprise about 1/3 of near-earth asteroids, are known to have volatiles such as water, carbon monoxide and CO_2 that could be released upon heating for industrial processes such as propellant production. Because volatiles will be a key target for utilization, surface samples will be brought into the habitat for study. Volatiles released during experiments within the habitat could pose a hazard to the crew. The presence of volatiles adds the possibility that central nervous system effects could be elicited by exposure to structurally simple, polar compounds (alcohol like).

Given the unique properties of dust and volatiles on celestial bodies such as asteroids, Mars, and the moon, minimal data on health effects of contact or airborne exposure, and the lack of a viable exposure standard for some of those bodies, there is a possibility that exposure could lead to serious respiratory, cardiopulmonary, ocular, central nervous system, or dermal harm during exploration-class missions, resulting in immediate or long-term health effects.

4.4.3 Risk of Performance Decrement and Crew Illness Due to an Inadequate Food System (Short Title: Food)

The Advanced Food Technology (AFT) Portfolio is responsible for optimizing methods required to prepare, preserve, package, stow, and ship the food while preserving the nutritional value and acceptability and minimizing use of flight resources. The retort, irradiation, and freeze-drying processes currently used to produce shelf stable products reduce the nutrient content, and degradation continues through storage at ambient conditions. The nutritional content of 109 flight food items is currently being measured after processing, after one year, and after three years of ambient temperature storage to determine whether they meet the nutrition requirements as specified by the nutrition standards and as determined through the Nutrition SMO mentioned above. Studies of the stability of food nutrients will identify vitamins and amino acids at risk for degradation in the space food supply, and characterize degradation profiles of the unstable nutrients.

Preliminary shelf life findings have indicated that the current food system is inadequate for long duration missions. A study investigating the effect of the ingredient formulation, the type of processing and packaging, and storage conditions has determined that no single solution will extend the nutrition and acceptability of the food system for longer duration missions. Hurdle approaches combining optimized formulation, packaging, processing, and storage solutions must be investigated. Methods to maintain food system acceptability and nutrition over long duration missions, including implementation of a bioregenerative pick and eat salad crop supplemental system, are also under investigation.

Reducing the flight resources required for the food system is a major goal due to the significant ratios of rocket size to mass of cargo delivered on an exploration mission. Nutrient dense foods must be developed to reduce the food and packaging mass and volume overhead. Food packaging materials must be developed that are compatible with novel processing technologies, minimize the mass and volume, and provide an adequate oxygen and moisture barrier to maintain the required shelf lives. These studies must provide solutions that overcome resource challenges during extended periods of food storage (i.e., 18 months for ISS, up to 5 years for a long duration mission having pre-positioned food) without compromising nutrition and acceptability.

4.4.4 Risk of an Incompatible Vehicle/Habitat Design (Short Title: Hab)

This risk can have both short-term and long-term negative effects arising from crewmembers performing tasks in physical working and living environments that are not designed to suit the crewmembers capabilities. This risk applies to any habitat designed for travel or operation outside Earth’s atmosphere wherein crew must work, including launch and transfer vehicles,

pressurized suits or other occupied and confined space (e.g., space station, non-Earth outpost, re-entry capsule, rovers). Examples of short-term effects include overexertion, difficulty in reading a checklist due to spacecraft vibrations or inadequate lighting, high temperatures in a module due to inefficient co-location of habitability-related hardware and excessive activities, difficulty donning a suit due to inadequate habitable volume, or difficulties communicating with fellow crewmembers due to high levels of noise in the cabin. Performance-related inefficiencies may include unnecessary translations between workstations to complete tasks, and increased task completion time due to difficulty in accessing equipment. Examples of the long-term effects include ergonomic injuries or cumulative trauma disorders that are a result of repetitive motions, sustained maintenance of awkward postures, inadequate workspace clearances resulting in frequent over-exertions, suit hardware requiring sustained performance at excessively high sub-maximal levels, and permanent hearing loss. Additionally, poor habitat design in conjunction with long-duration isolation may lead to the decreased quality of crew behavioral health (see also Risk of Adverse Behavioral Conditions and Psychiatric Disorders). Interacting with a vehicle or habitat environment that does not accommodate the crew along all their anthropometric ranges, and does not consider human capabilities and limitations, and how these may change during long-duration spaceflight could lead to injuries, crew frustration, and/or mission failure.

4.4.5 Risk of Inadequate Design of Human and Automation/Robotic Integration (Short Title: HARI)

This risk focuses on the appropriate integration of humans with highly autonomous and complex space systems, which includes robotic systems as well as space vehicles. NASA's future missions will involve more extensive interaction between humans and automated and robotic systems to accomplish mission goals in near-and deep-space exploration and during surface operations on near-Earth-objects and planetary surfaces. Human-robot teaming will extend to a variety of classes of robotic systems (including dexterous, heavy-lift and mobility systems). Robotic systems and their human interfaces must be designed to support all levels of human operation (e.g., direct manual control, teleoperation shared control, and supervisory control), while also supporting multiple robot operators in multi-agent team configurations, with those operators separated by time, space, or both. Automation will be an integral part of both ground and flight systems, in addition to being utilized within robotic systems. Future missions will demand that the complexity of operations will substantially increase. Similarly, the level of interaction between the flight crew, ground crew, robotic, and automated systems relative to today will also increase. Systems must be designed to support multiple operators, varying time delays between flight and ground crew, and increasing reliance on automation. Similarly, the integration of automation systems with their human users requires supporting a variety of role divisions: authority and autonomy can be differently allocated between human and automation, and the allocation may change dynamically depending on task or context. If automation/robotic agents are not appropriately integrated with crew, the inadequate design may lead to crew injuries, crew inefficiencies, and failed mission objectives.

4.4.6 Risk of Inadequate Human-Computer Interaction (Short Title: HCI)

This risk focuses on human-computer interaction (HCI) and information architecture designs that must support crew tasks, as well as how those interfaces will facilitate human performance and efficiency. Future exploration missions pose a paradigm shift for HCI in space operations, since unlike missions of the past, crews will have to operate autonomously, relying almost exclusively on the information systems available to them within the vehicle or habitat. Cockpits will feature primarily glass-based interfaces and communication delays will require crews to be largely self-sufficient. Information is presented most effectively when the user's interests, needs, and knowledge are considered in the design of interfaces. If information displays are not designed with a fully developed operations concept, fine-grained task analysis, and knowledge of human information processing capabilities and limitations, the format, mode, and layout of the information may not optimally support task performance. This may result in users misinterpreting, overlooking, or ignoring the original intent of the information, leading to task completion times that impact the timeline, necessitating costly re-planning and rescheduling, and/or task execution errors, which endanger mission goals, crew safety, and mission success.

4.4.7 Risk of Inadequate Task Design (Short Title: TASK)

This risk relates to the appropriate design of mission tasks, task flows, schedules, and procedures. This risk evaluates the right methods to develop effective operational tempo for crewmembers, which is driven by the scheduling and execution of mission tasks. The operational tempo affects workload and situation awareness of crewmembers: low workload levels have been associated with boredom and decreased attention to task, whereas high workload levels have been associated with increased error rates and the narrowing of attention to the possible detriment of tasks. Operational tempo, scheduling and execution of tasks is done in synchrony with ground control personnel, and this interaction must also be considered, particularly as crew autonomy increases. Effective task execution is also driven by the quality and presentation of procedures. When these procedures, be it written direction, checklists, graphic depictions, tables, charts or other guidance, are not designed to accommodate human capabilities and limitations, tasks may be executed inefficiently or incorrectly. Guidelines for designing task flow, schedules, and procedures that accommodate human capabilities and limitations are required, and for long duration missions, inadequate task design may result in increased workload, crew inefficiencies, and failed mission objectives.

4.4.8 Risk of Performance Errors due to Training Deficiencies (Short Title: TRAIN)

This risk focuses on the training of crew and mission support operators, both prior to and during flight, be it in microgravity or on another partial gravity surface. Currently, the training flow begins years before the mission, and crews have commented on the impact of early and drawn-out training on the level of training retention. Historically, spaceflight operations have mitigated potential execution errors in at least two ways: specially-trained crewmembers are assigned to missions or rotated into the operational environment when complex, mission-critical tasks must be performed; and, execution of tasks are closely monitored and supported by ground personnel who have access to far more information and expertise than an individual operator. However, emerging future mission architectures include long-duration operations in deep space. Simply

increasing the pre-mission ground training time will not address the need for increased training retention, and may even exacerbate the issue. Deep space operations do not allow for assignment of new crew or rotation of crew to ground for training. Further, delays in communication will have a disruptive effect on the ability of Earth-based flight controllers to monitor and support space operations in real time. Consequently, it is necessary to develop an understanding of how training can be tailored to better support long-duration deep space operations. This includes appropriate methods for Just-In-Time training, and the extent to which materials, procedures, and schedules of training should be modified. Performance errors of critical tasks may result in crew inefficiencies, failed mission objectives, and both short and long-term crew injuries.

4.4.9 Risk of Injury from Dynamic Loads (Short Title: Occupant Protection)

With the retirement of the Shuttle, future spacecraft systems may include launch-abort systems and parachute-assisted, capsule landings. Because of these potential design features, dynamic loads transmitted to the human may result in higher forces than currently experienced during spaceflight. The current standards and requirements do not adequately document the acceptable limits of forces and/or direction of force vectors which can be transmitted to the human without causing injury. Injuries may impair or prevent a crew-member from unassisted evacuation of the spaceflight vehicle after landing. Development of Agency-level human health and performance standards appropriate to occupant protection from dynamic loads, as well as development of the method(s) of meeting those standards in the design, development, and operation of mission systems, would reduce the likelihood of this risk so that crew injury or Loss of Crew (LOC) may be avoided or reduced. In addition, the Columbia Crew Survival Investigation Report cited inadequate upper body restraint and protection as a potential lethal event and recommended that future spacecraft suits and seat restraints should use state-of-the-art technology in an integrated solution to minimize crew injury and maximize crew survival in off-nominal acceleration environments (L2-4/L3-4) and should incorporate conformal helmets and neck restraint designs similar to those used in professional auto racing (L2-7). Because all crewmembers must endure dynamic phases of flight, detailed understanding of the human body response to such environments is critical. In addition, because spaceflight deconditioning causes decreases in bone strength, decreases in muscle strength, and increases in bone fracture risk, the criticality of this understanding is greater with longer duration spaceflight missions.

The Occupant Protection Team at NASA has developed a forward plan to develop new standards for protecting the crew during dynamic phases of flight. In collaboration with external peers in industry, academia and other government agencies, the Team will develop and validate the standards using a combination of data mining, testing, analysis, simulation and expert opinion.

4.5 SR

SR risks are categorized into cancer, late and early central nervous systems (CNS) effects, acute radiation sickness, and degenerative risks, which includes circulatory diseases and cataracts. Other known radiation effects may occur at higher dose than the extremes of the SR environment (e.g. acute mortality, lung toxicity, etc.) and therefore are not considered in SR research as being relevant to NASA. The radiation risks are inter-related in the sense that a common exposure is causative for each risk, competing risks on mortality of late effects occurs, and there are potential

antagonistic factors of the use of a biological countermeasure for one risk to another. The SR Element uses data from all funded research studies and provides the integrating component through development of risk assessment tools and design tools.

4.5.1 Risk of Radiation Carcinogenesis (Short Title: Cancer)

Near-term goals for cancer research focus on reducing the uncertainties in risk projections through the development of tissue specific models of cancer risks, and the underlying mechanistic understanding of these models, and appropriate data collection at the NSRL. In the long term, extensive validation of these models with mixed radiation fields and chronic exposures is envisioned and research on biological countermeasures and biomarkers will be pursued. Research on improving cancer projections has two major emphases:

1) testing the correctness of the National Council on Radiation Protection (NCRP) model and
2) reducing the uncertainties in the coefficients that enter into the cancer projection model. Research on the validity of the NCRP model relies on studies at the NSRL observing qualitative differences in biological damage between High Charge and Energy (HZE) nuclei and gamma rays and the establishment of how these differences relate to cancer risk.

There are distinct mechanisms of cancer induction across and within major tissue sites, and uncertainty reduction requires tissue specific risk estimates. NRA and NASA Specialized Center of Research (NSCOR) proposal selections focus on these major sites: lung, breast, colon, stomach, esophagus, the blood system (leukemias), liver, bladder, skin, and brain. There are differences in radiation sensitivity based on genetic and epigenetic factors and research in these areas aids the development of tissue-specific cancer models.

The approach to risk quantification and uncertainty reduction is based on modifying the current model for projecting cancer incidence and mortality risks for space missions. The cancer rate is the key quantity in the evaluation, representing the probability of observing a cancer at a given age and years since exposure. The life-span study of the Japanese survivors of the atomic bomb is the primary source for gamma ray data. More recently, however, meta-analysis of data for several tissue types from patients exposed to radiation or reactor workers has become available. These newer data are being used to check or replace the Japanese data. Other assumptions in the model are made with regard to the transfer of risk across populations, the use of average rates for the U.S. population, age, and age-after exposure dependence of risk on radiation quality and dose rate, etc.

Collaborative research with the Department of Energy (DOE) Low Dose Research Program remains a key component of the strategy. The DOE program focus is on low Linear Energy Transfer (LET) irradiation; collaborative grants have been selected from proposals that contain one or more Specific Aims addressing NASA interests using the NSRL. This research augments SR research with a number of grants that use state-of-the art approaches, i.e., genetics, proteomics, and transgenic animal models, etc.

Determining the shape of the dose-response model for cancer induction is a near-term focus that is enumerated in biological terms through various cancer gaps. In the NCRP model, the relationship between dose and response is linear and the slope coefficient is modulated by radiation shielding. Models of non-targeted cancer risk describe processes by which cells traversed by HZE nuclei or protons produce cancer phenotypes in regions of tissue not limited to the traversed cells. Non-targeted effects are the major mechanism that has been identified that is in disagreement with the NCRP model, and they show a sub-linear dose response. The implications of such a dose response for cancer risk are large since such a model predicts a reduced effectiveness for radiation shielding. The importance of mission length is also affected by the sub-linear dose response. For some cancer sites and exposure conditions, for example proton exposures, the NCRP model may be adequate. NSRL research is focused on reducing the uncertainties in the model through the establishment of tissue-specific models of human cancers, and on collection of data at NSRL for a variety of ground-based analogs for solar particle event (SPE) and galactic cosmic rays (GCR).

Systems biology models provide a framework to integrate mechanistic studies of cancer risk across multiple levels of understanding (molecular, cellular, and tissue), and are the most likely approach to replace the NCRP model. Systems biology models are being developed by the Risk Assessment Project and several NSCORs, and, in conjunction with data collection, will improve the descriptions of cancer risk, laying a framework for future biological countermeasure evaluations and biomarker identification.

4.5.2 Risk of Acute (In-flight) or Late Central Nervous System Effects from Radiation Exposure (Short Title: CNS)

A critical question for the current phase of research is to establish possible threshold doses for specific CNS risks. CNS risks from GCR are a concern due to the possibility of single HZE nuclei traversals causing tissue damage as evidenced by the light-flash phenomenon first observed during the Apollo missions. Also, as survival prognosis for patients irradiated for brain tumor treatment has improved, patients have shown persistent CNS changes at times long after treatment with gamma rays suggesting a possible CNS risk for a large SPE. Furthermore, animal studies of behavior and performance with HZE radiation suggest detrimental changes may occur during long-term GCR exposures. Currently, there is no projection model for CNS risks of concern to NASA. The values of possible thresholds for CNS risks and knowledge on how to extrapolate possible thresholds to individual astronauts is a key milestone in the long-term research plan.

4.5.3 Risk of Cardiovascular Disease and Other Degenerative Tissue Effects from Radiation Exposure (Short Title: Degen)

Recently, several epidemiological studies, including results from the atomic-bomb survivors and nuclear reactor workers, have identified an increased risk of stroke and coronary heart disease (CHD) for low-LET radiation at doses comparable to those of a Mars mission, or a lunar mission incurring a large SPE. Because the risk of heart disease is a recent finding, preliminary studies in these areas are seeking to establish possible distinctions, in mechanisms for this risk, between protons, HZE nuclei, and gamma rays. As an adjunct, SR will take advantage of studies by the

European Union in this area. These studies should present new insights into the nature of the low LET (gamma-ray) risk at low dose-rates comparable to space conditions, and should identify appropriate mouse strains to be used in future SR studies.

4.5.4 Risk of Acute Radiation Syndromes Due to Solar Particle Events (Short Title: ARS)

Mission operations, monitoring, and storm shelter provisions minimize the risk of a large exposure to crew members from a SPE. However, a variety of acute radiation syndromes would be of concern following an unavoidable large SPE exposure: radiation sicknesses, such as the prodromal risks, include nausea, vomiting, diarrhea, and fatigue. These effects are manifested within 4 to 24 hours post-exposure for sub-lethal doses, with a latency time inversely correlated with dose. Furthermore, there is a reasonable concern of a compromised immune system, due to high skin doses from an SPE or other in-flight factors, although the possibility of acute death through the collapse of the blood forming systems is negligible. One research emphasis is to pursue the role of the immune system in acute risks. Animal and cell culture models and possible countermeasure approaches to acute risks are expected to be distinct from those for cancer and other radiation risks. In the long-term, the SR will consider research on fertility, sterility, and hereditary risks from SR.

5 CONTENT IN THE HUMAN RESEARCH ROADMAP

The IRP contains detailed research plan information in a standard format, including a graphical depiction via PRR charts and specific information fields. Through the HRR the information is accessible to the public.

5.1 Risk Page

Each HRR risk, risk factor or concern item has a risk page with relevant information, including short title, risk statement, context, and mitigation strategy, as detailed below. A risk rating for DRMs, a link to the PRR chart, and a listing of the gap(s) that must be addressed before each risk is mitigated are also included on each risk page.

- Short Title: assigned to the risk as a matter of convenience and is used internally within HRP.
- Risk Statement: this is the HSRB-approved Risk Statement for each risk that concisely describes specific condition of relevance to human spaceflight missions and the negative outcomes that may potentially result.
- Context: this is the HSRB-approved Risk Context for each risk that briefly describes the what, when, where, how, and why of the risk or concern by stating the circumstances and scenario(s) considered, any known contributing factors, operational relevance, evidence or related issues to provide background information not captured in the risk statement.

- Mitigation Strategy: the approach strategy for the mitigation of the risk is outlined in this section. For instance, the strategy may be to first determine space normal physiology, then identify specific countermeasures.

Each risk's PRR chart, which shows the forecasted timeline of risk milestones for improving risk ratings, is accessed through the PRR tab on each risk page. At this time, only the Mars PRR is available in the HRR. The PRR Chart Overview, seen in Section 6, shows a general methodology used to develop the chart. The current risk rating (HSRB-approved if available) is used as the starting point. Specific highlighted risk milestones shown on the top line for the Mars DRM represent thresholds in movements of the risk ratings (e.g., red to yellow to green). Section 6 contains a PRR overview and example chart.

5.2 Gap Page

Each gap in knowledge or in the ability to mitigate each risk, as identified by the HRP Elements, is listed in the IRP. Each gap page includes a description of the gap, which typically contains the initial state and approach, a target for closure, and a listing of the task(s) that are required to address the gap.

5.3 Task Page

Each task, as identified by the HRP Elements, required to address a gap is named in the IRP. In some cases, a task may address multiple gaps within a risk or gaps across multiple risks. Each task page typically contains information on the responsible HRP Element, Principal Investigator (PI), procurement method, the task's overall aims, resources needed (e.g., ground analog or flight), and deliverable(s). The level of detail in the task information may depend on the task's maturity level, with those tasks in the near future typically having higher fidelity and more complete information compared to tasks planned farther in the future.

In some cases, organizations outside the responsible Element, such as other HRP Elements, other divisions within NASA, the National Space Biomedical Research Institute (NSBRI), or even an international partner, are responsible for implementation of specific tasks in the research plan. These collaborating organizations are identified within this section and the responsible Element will coordinate with the appropriate organization in these cases.

Each deliverable in the IRP is classified by category and subcategory. The deliverable categories and subcategories are listed in the table below and briefly described in the text that follows. This information is verbatim from HRP-47069, and is reprinted in the IRP as a matter of convenience for the reader.

TABLE 1. CATEGORY OPTIONS FOR DELIVERABLES

Category	Subcategory	Example Customers	Example Deliverables
Requirement or Guideline	Vehicle/Suit Design	Vehicle/Mission Definition & Development Program	Suit Design Requirements
	Flight Rule/ MRID/Practice Guidelines	Medical/Mission Operations	Procedures, Best Practices
Technology or Tool	Systems Solutions, Prototype Hardware or Software	Medical Operations, Vehicle/Mission Definition & Development Program	Food packaging technologies, In-flight Blood Analysis Technology, User interface prototype
	Clinical Care, Medical Informatics, Human Performance Data Collection Methods	Medical Operations, Vehicle/Mission Definition & Development Programs	Training Protocol for Effective Medical Operations, Questionnaires
	Computational Models, Software	Medical Operations, OCHMO, Vehicle/Mission Definition & Development Program	Radiation Risk Assessment models, Digital Astronaut models, Net habitable volume (NHV) model
	Database	Human Research Program, Medical Operations, Vehicle/Mission Definition & Development Program	Database created by gathering existing data
	Simulation	Medical Operations, Vehicle/Mission Definition & Development Program	Decision support tool, Integrated Medical Model
Countermeasure	Prescription	Medical Operations, OCHMO	Integrated Resistance and Aerobic Training Study
	Protocol	Medical Operations, OCHMO	Prebreathe Protocol for Exploration Systems
	Prototype Hardware or Software	Medical Operations, OCHMO, Vehicle/Mission Definition & Development Program	Prototype treadmill harness for use during exercise countermeasures, computer-based training for stress management
	Pharmaceutical or Nutritional Supplement	Medical Operations, OCHMO, Vehicle/Mission Definition & Development Program	Pharmaceutical recommendations resulting from Vitamin D Study
Standard	Update	OCHMO	Nutrition Standard Update
	New	OCHMO	Lunar Dust PEL
Risk Characterization , Quantification	Evidence	OCHMO, HSRB	NRA final report, Evidence Report, Conceptual Model
Study Results	Customer Requested Study or Analysis	Vehicle/Mission Definition & Development Program	Trade Study Analysis Results and Recommendations

Requirement or Guideline

The "Requirement or Guideline" deliverable is chosen when a task will result in information that is relevant to a requirement (or requirements set) or guideline owned by another program or to another Element. For example, the task may end up informing the requirements on the lighting spectrum in the vehicle, or the results may apply to the radiation shielding design, or conclusions may be reached that apply to the food system from nutritional risk work. These deliverables often feed the design of the vehicle and its sub-systems. As inputs to requirements, they primarily are applied in the Systems Requirements Review (SRR) timeframe.

Technology or Tool

The "Technology or Tool" deliverable covers a broad spectrum of developments that includes hardware, software, systems solutions, new processes, inventions, innovative methods, design tools, databases, computational models, or systems simulations. These deliverables support HRP research, as well as external customers.

Countermeasure

A "Countermeasure" deliverable is a specific protocol that is developed and validated to prevent or reduce the likelihood or consequence of a risk. Countermeasures may be medical, physical, or operational entities, such as a pharmaceutical or nutritional supplement, prototype hardware or software, or specific exercise routines, respectively. A countermeasure deliverable is usually specific and extensive enough to require validation in spaceflight. For instance, if a ground task results in a spaceflight task that is called a "flight validation study," it likely is a countermeasure. Note that in some cases the countermeasure will also affect mission operations (in areas like timelines). Some general direction on this, however, is that the countermeasure usually does not affect the design of the spacecraft, and is applied in the mission operations phase as a solution to a problem; thus, the countermeasure deliverables generally affect the mission operations PDR or CDR phases.

Standard

A "Standard" deliverable often begins as a Risk Characterization, Quantification activity. Preliminary information about a risk is often incomplete. HRP would not be in a position to recommend a standard update, but preliminary information would represent a significant step toward such a recommendation. Risk Characterization tasks can feed into other tasks that also have information for standards, or they can be combined with other "Standard" deliverables to result in a recommendation for a new or updated standard.

A "Standard" deliverable is mandated when the program is ready to provide the OCHMO with a new standard or a recommended update to an existing health or performance standard. A key test of the "Standard" as a deliverable is that the program is ready to write the text for the recommended standard update. Since the standards are applied in a broad spectrum for design and operations, these deliverables can be linked to any of the system design or mission

operations milestones. They should be applied as early as possible in the design phase or mission operations development phase, so, most often, they are necessary prior to SRR.

Risk Characterization, Quantification

When a task results in information that must be considered by the HSRB, medical operations community and/or OCHMO, this deliverable is used. This deliverable is applicable when it impacts the rating of the likelihood or consequence of a risk. It is also applied when the results of the study are anticipated by the space medical operations community.

Study Results

A study or analysis is requested by an HRP customer or Element. This is often a trade study that includes analysis, results and recommendations. Data mining or literature review tasks typically produce this type of deliverable.

6 PRR CHART

PRR Chart Overview:

HRP Strategy for Risk Reduction

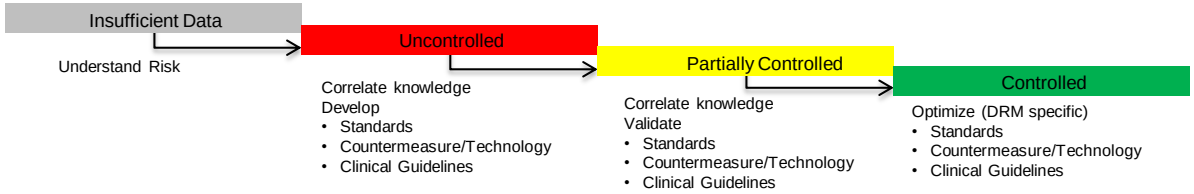
Research and Technology Development Plans

- Requires emphasis on risk reduction and drivers (e.g., research priorities, vehicle design, mission architecture, schedule)
  - Initial and desired state of knowledge or mitigation (gaps)
  - Tasks/studies required to close the gaps including schedule
  - Logic and relationship of all tasks and deliverables leading to gap closure and risk reduction

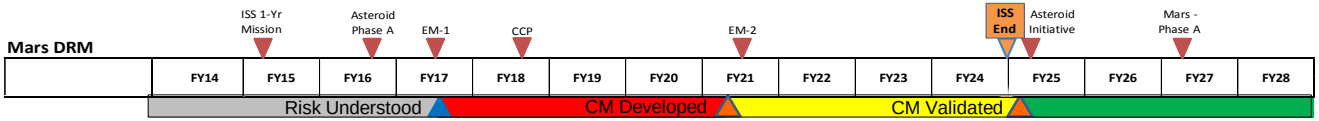
Gap Closure

- Requires demonstration of significance to risk reduction
  - Completion of deliverables per the HRP Integrated Research Plan
  - Scientific assessments
    - Changes to evidence/knowledge base
    - Impacts to risk posture
    - Replanning

Risk Reduction

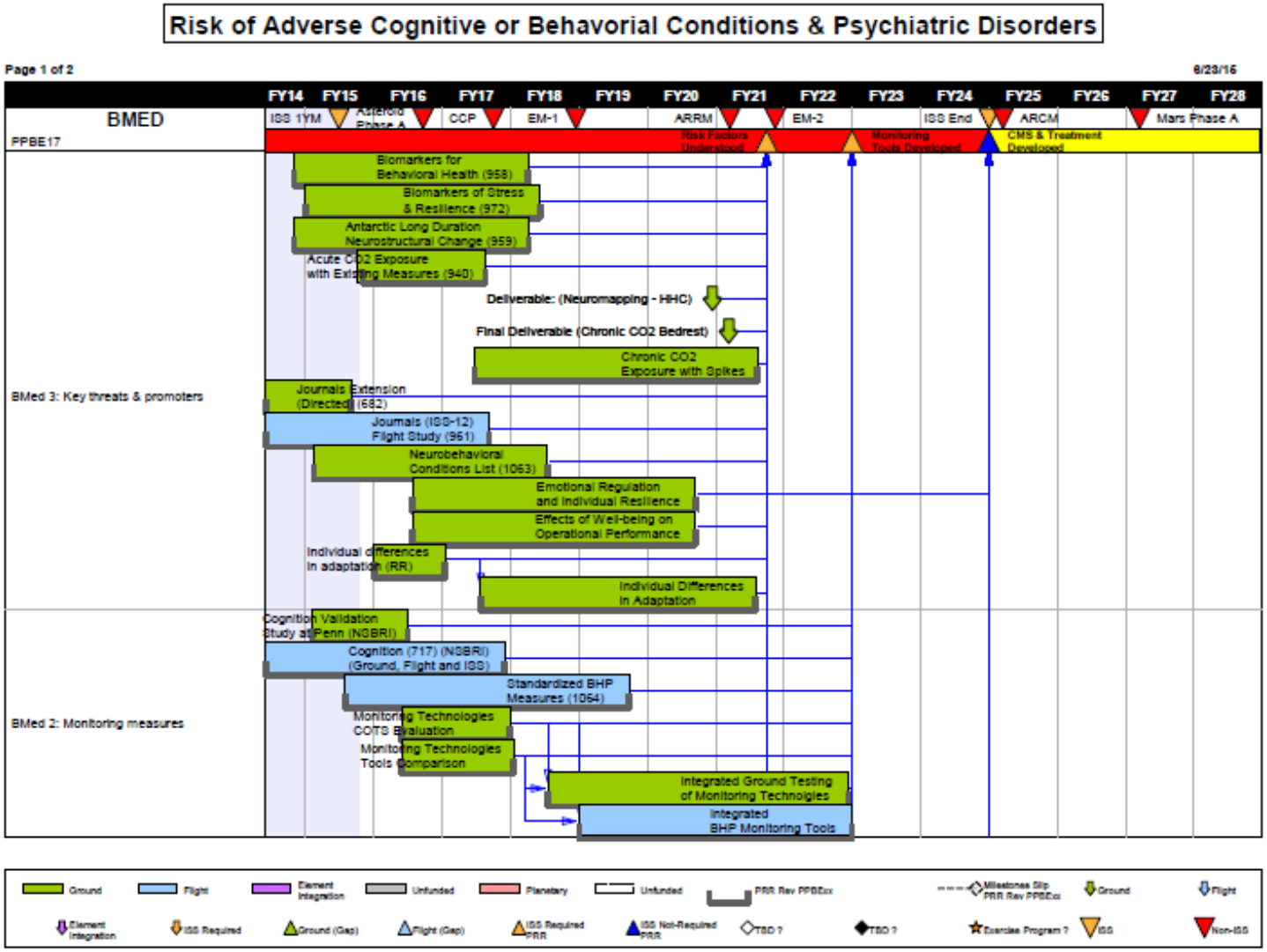


Path to Risk Reduction (example)



Verify that this is the correct version.

PRR Chart Example:



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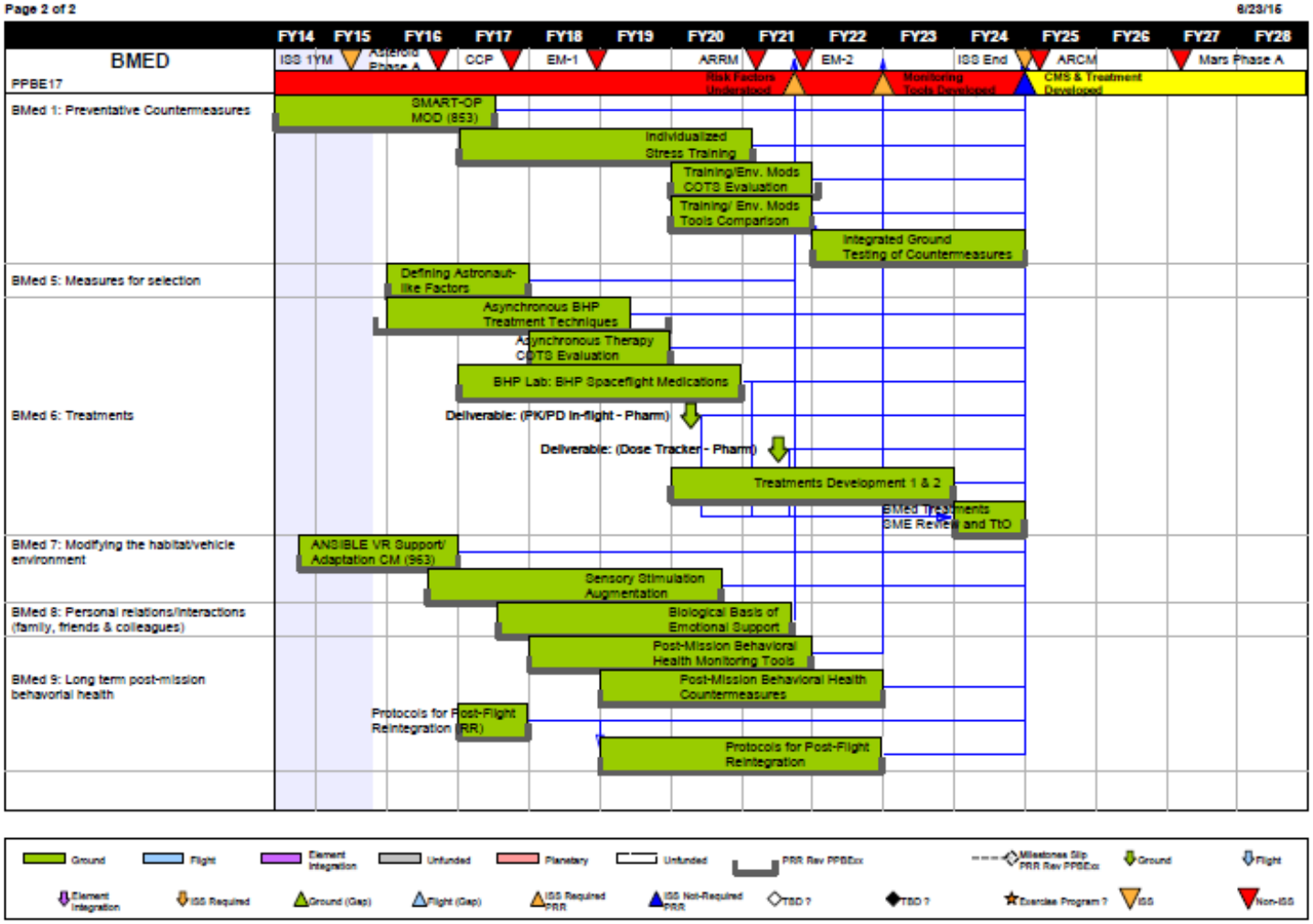
Risk of Adverse Cognitive or Behavorial Conditions & Psychiatric Disorders



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APPENDIX A - LINK TO HUMAN RESEARCH ROADMAP

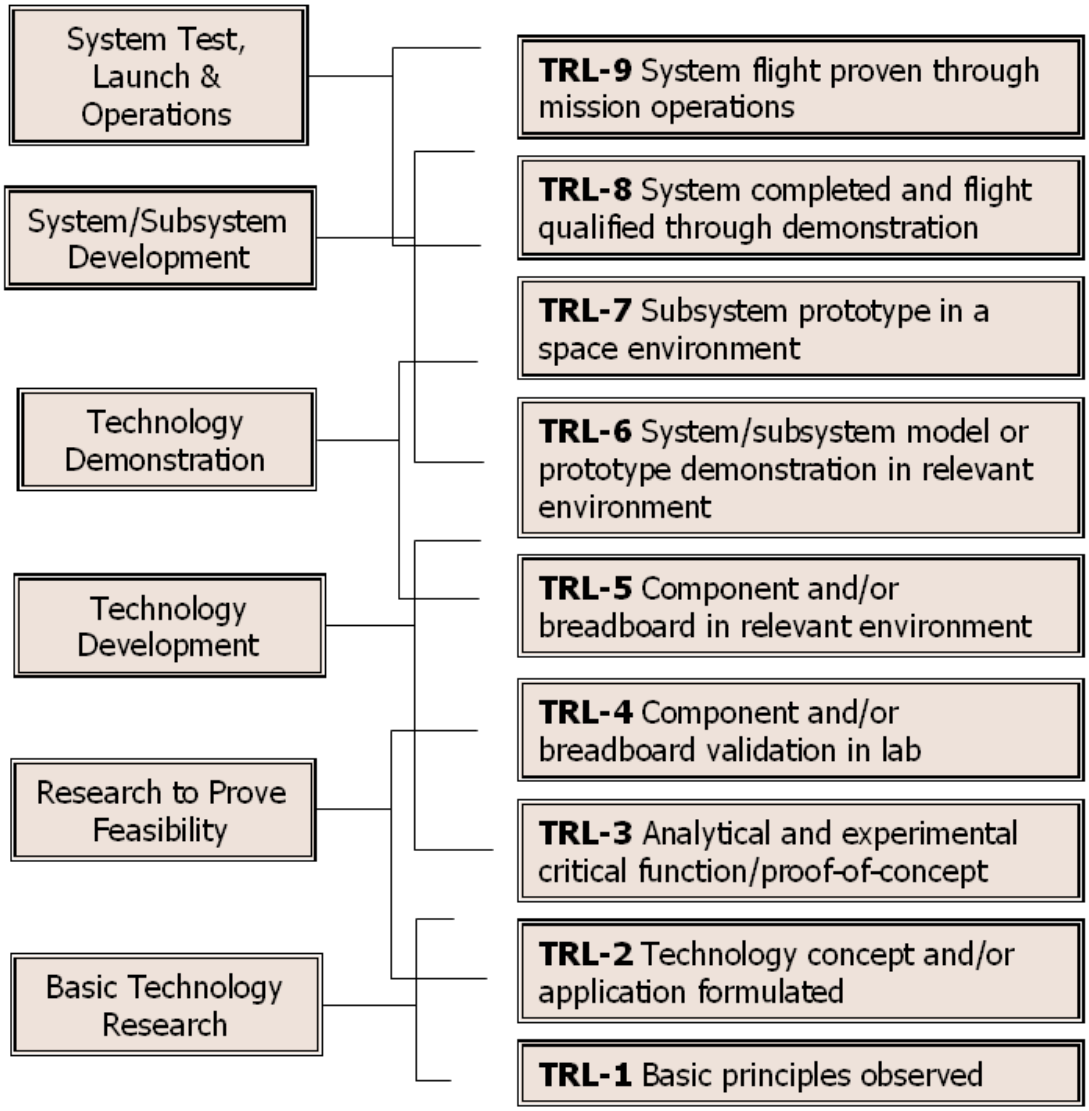
Risk, gap and task information that was formerly contained in Appendix A is now located in the HRR:

http://humanresearchroadmap.nasa.gov/

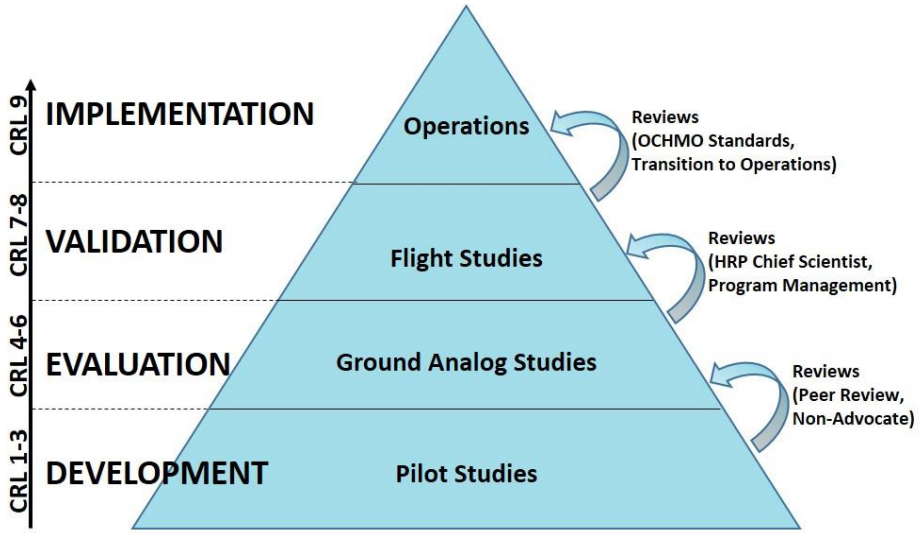
HHC Infrastructure Gaps are not linked to any of the HRP risks; they may be found by searching "GAPS" for HHC1, 2, 3 or 5.

APPENDIX B - TECHNOLOGY READINESS LEVELS (TRL) AND COUNTERMEASURE READINESS LEVELS (CRL)

Definition of Technology Readiness Levels (TRL)



Definition of Countermeasure Readiness Levels (CRL)



APPENDIX C - LIST OF ACRONYMS

A

AFT	Advanced Food Technology

B

BEO	beyond Earth orbit
BHP	Behavioral Health and Performance

C

CDR	Critical Design Review
CHD	coronary heart disease
CHMO	Chief Health and Medical Officer
CMO	Chief Medical Officer
CNS	central nervous system
CO_2	carbon dioxide
CPG	Clinical Practice Guideline
CR	Change Request
CRL	Countermeasure Readiness Level

D

DCS	decompression sickness
DOE	Department of Energy
DRM	Design Reference Mission

E

EVA	Extravehicular Activity
ExMC	Exploration Medical Capability

F

FAP	Flight Analogs Project
Fe°	elemental iron
FOR	Factor of Risk

G

GCR	galactic cosmic rays

H

H_2O	water
HCI	human-computer interaction
HEOMD	Human Exploration and Operations Mission Directorate
HERA	Human Exploration Research Analog
HHC	Human Health Countermeasures
HIDH	Human Integration Design Handbook
HRP	Human Research Program
HRPCB	Human Research Program Control Board
HRR	Human Research Roadmap
HSRB	Human Systems Risk Board
HZE	High Charge and Energy

I

ICP	intracranial pressure
IOM	Institute of Medicine
IRP	Integrated Research Plan
ISS	International Space Station
ISSMP	International Space Station Medical Projects
ITI	intratracheal instillation
IVD	intervertebral disc

J

JSC	Johnson Space Center

K

L

LEO	low Earth orbit
LET	Linear Energy Transfer
LSAH	Lifetime Surveillance of Astronaut Health
LOC	Loss of Crew

M

MRID	Medical Requirements Integration Document

N

NASA	National Aeronautics and Space Administration
NCRP	National Council on Radiation Protection
NRA	NASA Research Announcement
NSBRI	National Space Biomedical Research Institute
NSCOR	NASA Specialized Center of Research
NSRL	NASA Space Radiation Laboratory

O

OCHMO	Office of the Chief Health and Medical Officer
OI	orthostatic intolerance

P

PCA	Program Commitment Agreement
PD	pharmacodynamics
PDR	Preliminary Design Review
PEL	permissible exposure limit
PI	principal investigator
PK	pharmacokinetics
PRD	Program Requirements Document
PRR	Path to Risk Reduction

Q

R

R&TD	research and technology development
RCAP	Research and Clinical Advisory Panel
REV.	Revision
RFP	Request for Proposal
RID	Review Item Discrepancy
RMAT	Risk Management Analysis Tool

S

SBIR	Small Business Innovation Research
SHFH	Space Human Factors and Habitability
SMO	Supplemental Medical Objective
SPE	solar particle event
SR	Space Radiation
SRR	System Requirements Review
STD	Standard

T

TBD	to be determined
TRL	Technology Readiness Level

U

UPCG	Unique Processes, Criteria, and Guidelines

V

VIIP	visual impairment/intracranial pressure
VO_2	oxygen consumption
VO_2max	Maximal Oxygen Consumption

WXYZ