Human Research Program
Integrated Research Plan

July 2012

Revision D

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058

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Integrated Research Plan

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PREFACE

HUMAN RESEARCH PROGRAM INTEGRATED RESEARCH PLAN

The Integrated Research Plan (IRP) describes the portfolio of Human Research Program (HRP) research and technology tasks. The IRP is the HRP strategic and tactical plan for research necessary to meet HRP requirements. The requirement to produce an IRP is established in HRP-47052, Human Research Program - Program Plan, and is under configuration management control of the Human Research Program Control Board (HRPCB).

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1.0 INTRODUCTION AND BACKGROUND

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 because it provides knowledge and tools to mitigate risks to human health and performance. Risks include physiological effects from radiation and hypogravity environments, 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, NASA will face unknown and unacceptable risks for mission success and post-mission crew health.

This Integrated Research Plan (IRP) describes (1) HRP's approach and research activities that are intended to address the needs of human space exploration and serve HRP customers and (2) the method of integration for risk mitigation. The IRP describes activities that can be conducted with the resources available to the HRP, as well as activities that would be performed if additional resources were available. The timescale of human space exploration is envisioned to take many decades. The IRP illustrates the program's research plan through the timescale of early beyond Earth orbit (BEO) missions of extended duration.

The IRP serves several purposes for the Human Research Program. The IRP…

- 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 research activities to expected outcomes and need dates;
- shows the interrelationships among research activities that may interact to produce products that affect multiple HRP Elements, Projects or research disciplines;
- accommodates the uncertain outcomes of research and technology activities by including decision points 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; and
- shows the budgeted and unbudgeted research 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.

In 2011, the content of what was formerly Appendix A was transferred to the Human Research Roadmap (HRR): http://humanresearchroadmap.nasa.gov/.

1.1 CONTEXT OF THE INTEGRATED RESEARCH PLAN

There are three types of foundational documents to the HRP:

1. Program Requirements Document (PRD)
2. Evidence Reports
3. Integrated Research Plan (IRP)

The relationship of these HRP documents is illustrated in Figure 1.1; the content and purpose of these and other documents are described in the sections that follow.

National Aeronautics and Space Administration

HRP Requirements and Content Alignment

Human Research Program

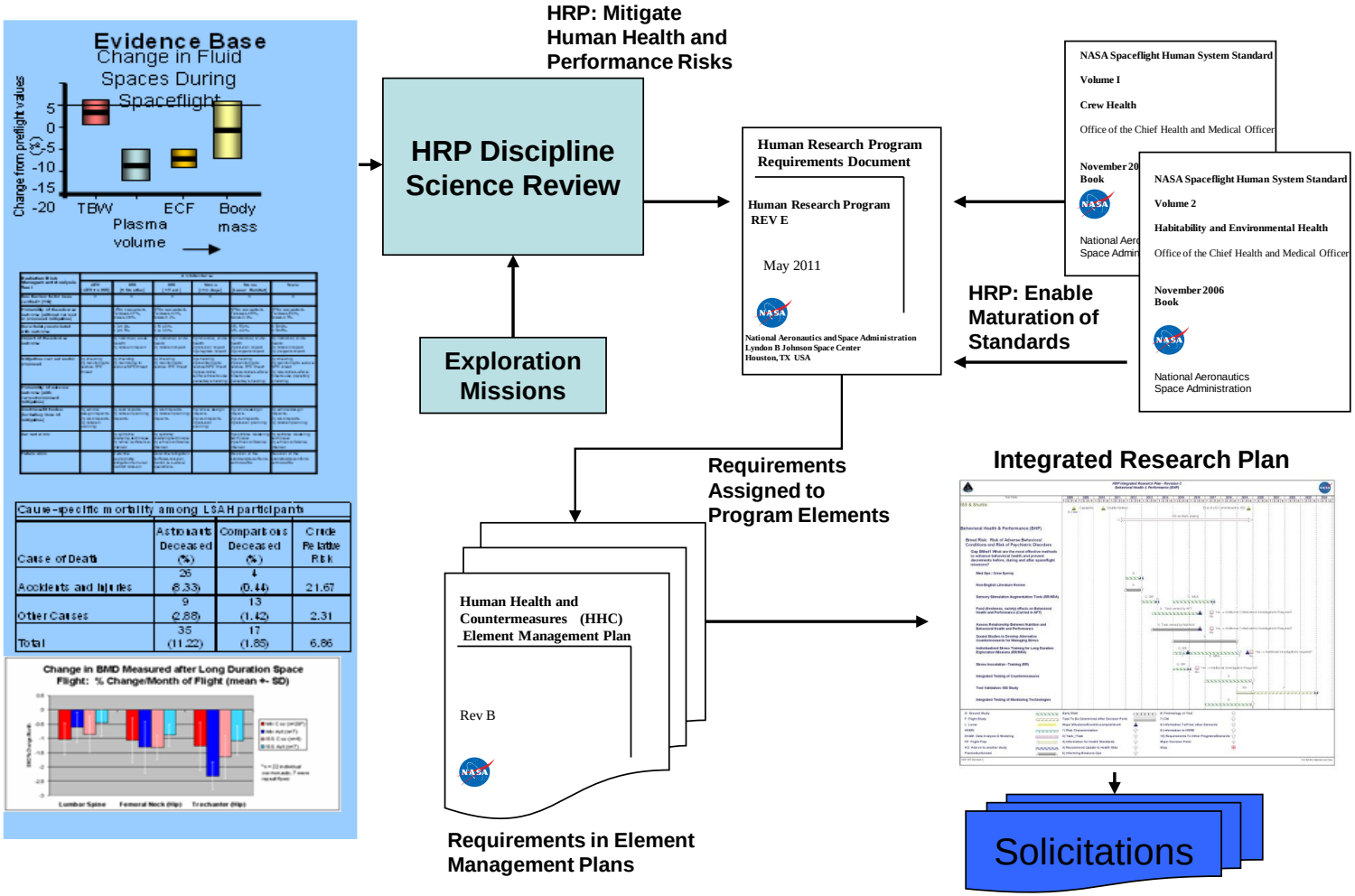

Figure 1.1: HRP Requirements and Content Alignment

1.1.1 MANAGEMENT ARCHITECTURE

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

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. At present, the HRP has identified 32 risks and risk factors that require research. These 32 risks and risk factors are listed in the HRP PRD.

The NASA Chief Health and Medical Officer is responsible for maintaining NASA's Space Flight Human Systems Standards ((NASA-STD-3001, Vols 1 & 2). The Chief Medical Officer developed a system to review and document all instances where standards cannot be met, and the plan to mitigate the risks associated with unmet standards. All instances where standards are not met can be categorized as risks to the human system. A Risk Management Analysis Tool (RMAT) was developed to describe each risk in greater detail, including: context, evidence, likelihood, consequence, and mitigation strategy. Information in the RMAT is provided within the context of different mission scenarios. To complement the RMAT, a Master Logic Diagram (MLD) is developed to identify the most important factors that contribute to a particular risk.

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 which research gaps are listed in the IRP. Ideally gaps listed in the IRP should correspond to one or more risk factors outlined in the MLDs. However, in many cases the subject matter experts selected research and development activities they considered most important prior to the availability of MLDs. The RMAT and MLD are defined in greater detail in section 1.4.1.

The IRP also defines the tasks that will provide the deliverables required to fill the gaps. Research tasks are targeted at better defining a risk, or developing mitigation strategies to reduce the risk to an acceptable level. Common deliverables include recommended standards (such as Permissible Exposure Limits), flight rules (such as avoiding certain exposure levels), processes, countermeasures and technology. A major criterion for selection of a specific task is how well the proposed research provides deliverables toward closure of the gap. Specifications for the deliverables are agreed upon with customers and stakeholders of HRP products through the use of Customer-Supplier Agreements. Tasks are solicited through NASA Research Announcements, the Small Business Innovation Research program (SBIR), NASA Request for Proposals, etc., or are directed by HRP management.

After the deliverables are provided, the gap is reassessed for the need for more a) knowledge or b) mitigation capability. Further rounds of research are performed until HRP and its customers agree that the gaps are adequately closed.

1.2 PROGRAM REQUIREMENTS DOCUMENT

As a program within the Human Exploration and Operations Mission Directorate (HEOMD), HRP objectives are identified in the HRP Program Commitment Agreement (PCA). Exploration program

requirements are merged with applicable human system risks forming the requirements for the HRP, as documented in the PRD.

The PRD decomposes those requirements into lower level requirements that are then allocated to the HRP Elements. 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. The HRP comprises the following major Program Elements: Behavioral Health and Performance (BHP), Exploration Medical Capability (ExMC), Human Health Countermeasures (HHC), ISS Medical Projects (ISSMP), Space Human Factors and Habitability (SHFH), and Space Radiation (SR). Each Element incorporates its respective PRD requirements into its specific Element management plan. The Elements subsequently derive a research plan to address the requirements.

1.2.1 STANDARDS

The PRD requires that the HRP make recommendations for updates to the Space Flight Human System Standards, NASA-STD-3001, Volumes I (Crew Health) and II (Human Factors, Habitability and Environmental Health), and the Human Integration Design Handbook (HIDH, NASA/SP-2010-3407).

NASA-STD-3001 Volume I describes Levels of Care required for human spaceflight missions, Permissible Exposure Limits, Permissible Outcomes, and Fitness for Duty Standards for crewmembers on exploration missions, among other things, and was first baselined on March 5, 2007, by the Office of the Chief Health and Medical Officer (OCHMO). Essentially, these are the definitions of acceptable levels of risk for human health and performance associated with spaceflight. By comparing these requirements with the existing evidence and knowledge base, the HRP can identify and quantify the risks associated with human exploration missions, and derive the research necessary to lower the risk.

NASA-STD-3001 Volume II provides the comprehensive set of human factors, habitability and environmental health requirements. These requirements must be met by all NASA programs in the development of vehicles and supporting equipment utilized in human spaceflight exploration. The HIDH is the companion document to Volume II. The HIDH is not a standard, yet provides background data, lessons learned and offers recommended design solutions for meeting the requirements of Volume II. Through comparison of the requirements in Volume II (and the content of the HIDH) with the state of the art in engineering design, the HRP can identify areas where research is necessary to help system development programs meet these requirements.

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.

1.2.2 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 CHMO's Human System Risk Board (HSRB) to identify risks requiring research. The PRD allocates 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.

1.3 EVIDENCE REPORTS

The HRP Evidence Reports document WHY the risks are contained in the PRD. It is a record of the state of knowledge for each risk in the PRD and, therefore, provides bases for analyses of the likelihoods and consequences for each of the risks. The Evidence Reports make important data accessible and available for periodic review. The HRP has published all 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 that is aimed at a scientifically-educated, non-specialist reader. The documentation is broken into the following parts:

The body of each risk evidence report contains a narrative discussion of the risk and its supporting evidence:

1. Declarative statements concerning the risk are supported by a description of the evidence, whether published or unpublished.
2. Relevant published references are listed at the end of the report.
3. Data that are significant or pivotal are summarized in text, tables, and charts in sufficient detail to allow the reader to critique and draw conclusions, especially when a published reference is not available.
4. In a similar fashion, the authors indicate, as appropriate, whether the data are from human, animal, or tissue/cell/molecular studies.
5. Evidence from spaceflight (including biomedical research, Medical Requirements Integration Document [MRID] data, and operational performance or clinical observations) is presented first, followed by ground-based evidence (including space analog research and non-space analog biomedical or clinical research).
6. When evidence is from ground-based studies, authors discuss why these results are likely to be applicable in the space environment, offering available validation information for the use of these ground-based systems.

The National Academies of Sciences Institute of Medicine (IOM) reviewed the risk reports to validate that they provide sufficient evidence that the risk is relevant to long-term space missions. Their conclusions and recommendations are given in the IOM publication, *Review of NASA's Human Research Program Evidence Books. A Letter Report*, Washington DC: The National Academies Press, 2008.

As new evidence is gathered, the Evidence Reports will be updated. 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.

1.4 THE INTEGRATED RESEARCH PLAN

1.4.1 Risks

The PRD defines the criticality metric for each HRP risk. The criticality metric is based on the degree to which the current state of knowledge about a risk will prompt the HRP Program Manager to recommend, in a forum such as the HSRB, "no-go" for undertaking a mission.

Each risk heading in the HRR is labeled with an abbreviated version of the lunar, near-earth asteroid (NEA), and Mars criticalities. These categories are intended to encompass the range of possible future Design Reference Missions (DRM).

1.4.1.1. Risk Management Analysis Tool (RMAT)

The HRP uses the RMAT to document information that influences the criticality rating of each risk and to provide a standard format to assess progress toward mitigating each risk. The RMAT is complemented by a MLD that is a visual representation of the set of contributory risk factors and events.

1.4.2 TASKS REQUIRED TO FILL THE GAPS (WHAT)

For each risk, the appropriate HRP Elements identified gaps in the risk's state of knowledge and NASA's ability to mitigate the risk. Further, the HRP Elements identified specific research tasks required to fill each gap and the product(s) resulting from the tasks. 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. This IRP lays out the risk, gaps, tasks, and resulting deliverables in a notional schedule tied to the appropriate Exploration milestones for which the products will be needed. Additional information for most currently funded tasks can also be found in the Task Book (http://taskbook.nasaprs.com/Publication/welcome.cfm)

The rationale for the selected approach is documented in the text portions of the IRP. This plan includes activities that are more than research or technology development. In some cases, the activities reported in this document are not explicitly "research" or "technology development," but are included to ensure logical completeness in describing those activities necessary to mitigate the risks. Examples are data mining activities, the results of which are pivotal in defining further steps in the research path, and hardware evaluations that would further the engineering approach to risk mitigation.

Key Decision Points are built into the IRP, wherein the HRP will evaluate data with respect to closing the research gap, as well as the impact on the overall likelihood or consequence of the risk. The results of this analysis will help formulate the next steps. In some cases, likelihood with existing countermeasures will not be high enough to warrant proceeding with more research. This risks-gaps-tasks-deliverables detail is required to ensure completeness in addressing the risks.

1.4.3 SCHEDULE DRIVERS (WHEN)

The IRP describes a plan of knowledge production and technology development to address risks associated with human spaceflight. As new knowledge is gained, the required approach to research and development may change. The IRP attempts to describe a plan of research looking forward many years into the future. The fidelity of the IRP is quite high in the near term (2012-2015), 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 from the previous year.

1.4.4 RESEARCH PLATFORMS (WHERE)

The HRP uses various research platforms and data sources to address gaps in knowledge. Historical data, derived from ground and spaceflight studies, form the basis of the HRP Evidence Reports, with

the intention of ensuring that the HRP does not duplicate effort already expended. Many of these activities appear in this IRP as "data mining," although not explicitly "research."

Data mining involves gathering and analyzing data from historical spaceflights via the Long-term Surveillance of Astronaut Health (LSAH) and other sources, spaceflight operational data (e.g. landing performance and simulator performance data) to identify possible correlation with physiologic or psychological function, and relevant data from ground studies (NASA─sponsored and otherwise).

The HRP utilizes the International Space Station (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 both validate potential countermeasures and as an analog for long-duration Mars missions.

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 2020 levy significant constraints on available flight resources; thus some research is accelerated to take advantage of these vehicles while they are available. However, since not all research that requires the ISS can be accomplished by 2020, the HRP will continue to plan use of the ISS as a viable research platform should the vehicle retirement be extended beyond the 2020 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.

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. Several analogs often will be required to fill a gap, and, in all cases, analog findings are validated in the spaceflight environment.

The HRP Flight Analogs Project (FAP) coordinates utilization of ground based research analogs to complement space research. Throughout the IRP, tasks requiring the use of specific analogs are identified. The bed rest analog mimics some of the physiological changes induced by degrees of weightlessness. The NASA Extreme Environment Mission Operations (NEEMO) analog and Antarctic missions provide mission-like settings and interactions that incorporate the constraints of working in extreme environments. The Haughton-Mars and Devon Island analogs provide rugged terrain and mission-like interactions to address specific lunar surface system concepts related to Extravehicular Activity (EVA) and other factors related to behavioral health and performance. In some cases, the HRP also utilizes operational mission environments, such as the Phoenix Mars Scout Lander, to obtain data relevant to the behavioral health and performance of the ground crews supporting long─duration spaceflight missions. Such data provide valuable lessons for future exploration missions. Isolation chambers also provide mission-like ground-to-crew and crew-to-crew interactions that facilitate behavioral studies of team cohesion, workload, fatigue, and sleep. The NASA NSRL is a unique ground-based analog. This facility is owned and operated by the Department of Energy's (DOE) Brookhaven National Laboratory, under a contract with the HRP. HRP utilization of the NSRL is managed by its Space Radiation Element.

1.4.5 FUNCTIONAL DEFINITION OF SPACE NORMAL

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. For example, one of the environmental characteristics of concern is the relatively small force of gravity on the Moon, which is approximately one-sixth of that on Earth. "Space normal" is defined for this document as the normal human response to prolonged spaceflight. 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. Thresholds, non-linearities, and system-system interactions or dependencies are all likely to affect these responses. These things will certainly be studied in crewmembers participating in exploration missions; however, 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) revise crew health standards if that state is medically unacceptable,
3) if unacceptable, then determine physiological mechanisms of action, and
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 space radiation, 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.

Rigorous definition of space normal for any aspect of human physiology will ultimately require flight and post-flight data. Ground─based analogs are often used to prepare for, or in lieu of flight studies.

1.4.6 ELEMENTS AND PORTFOLIOS RESPONSIBLE FOR THE RESEARCH (WHO)

Each risk is allocated to one of the research Elements within the HRP, and the IRP identifies which Element is responsible for the identified risk. Three of the HRP Elements are single-portfolio Elements: BHP, ExMC and SR. Two HRP Elements, HHC and SHFH, are multi-portfolio Elements. Portfolios in the HHC element include: Cardiovascular and Vision, Exercise and Performance, Multisystem, Bone, and Technology and Infrastructure. The following HHC abbreviations are used throughout the IRP to designate the responsible project: DA (Digital Astronaut), and FAP (Flight

Analogs Project). The following abbreviations are used to designate the responsible SHFH portfolios: AEH (Advanced Environmental Health), AFT (Advanced Food Technology), and SHFE (Space Human Factors Engineering).

The HRP's intent is that each study is procured through competitive means, i.e., NRA, Request for Proposal (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 the HRP Science Management Plan (HRP-47053). The current and 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 the Science Management Plan.

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.

Each Element, Portfolio or Discipline within the HRP will be reviewed by an independent Standing Review Panel. The Panel's primary responsibility is to review the Element Research Plan and provide recommendations on the scientific or technological approach and portfolio content. Those Element research plans ultimately serve as the input to the IRP. Modifications to Element research plans will result in modifications to the update of the IRP.

1.4.7 DELIVERABLES OF THE RESEARCH AND TECHNOLOGY (DELIVERABLES)

The focus of this document is to identify deliverables necessary to complete the exploration missions. The ISS is used as a platform to conduct research aimed at mitigating risks to the exploration missions. Some of the research may identify countermeasures, engineering, or operational solutions that would enhance the ISS and reduce risk in use (including to users) of that platform. In those cases, the HRP identifies the necessary deliverables and insertion points for the ISS.

Human health and performance risks can best be mitigated through space system design. The HRP works closely with the human exploration programs to communicate the areas of human health and performance risks, and to help inform engineering and development of the vehicle systems. Mitigation of many human health and performance risks can be accomplished through engineering design and operational constraints, and does not need further research. Decision points in the research schedules are placed to evaluate the adequacy of the approach, research results, and deliverables to meet the intended application.

The first and most desirable approach to mitigating a human health and performance risk is to engineer the risk out of the system. HRP research is intended to reduce the uncertainty in the risk and free mission timelines and design from unnecessary conservatism. To facilitate risk avoidance, the HRP identifies requirements for crew selection, and for vehicle or mission design.

Some human health and performance risks can be mitigated through application of special space medicine operations procedures. The HRP works closely with the Space Medicine Division at the Johnson Space Center (JSC) to evaluate the relative risks and to determine if the risks can be mitigated through known procedures. This coordination occurs through HRP participation on the HSRB. This board was established by the CHMO with chairmanship delegated to the JSC Chief Medical Officer. Members of this board consider the range of human health and performance risks and identify those that can be mitigated through operational procedures vs. those that require further research. The risks addressed in this IRP are those identified by the HSRB as requiring research. The "inform medical

operations" deliverables are the results of board discussions, and research results are integrated into medical requirements or flight operations procedures. The HSRB is also used to evaluate the "deliver countermeasure" deliverable to ensure countermeasures can be adequately transitioned to medical practice.

The HSRB is also used to evaluate data at various decision points in the research. The deliverables identified in the plan as "information to the HSRB" utilize the board to concur with the next steps in the research plan.

Several other deliverables are identified throughout this IRP. Two designations are used for standards deliverables. The deliverable to "inform standards" represents the HRP's intent to communicate information to the OCHMO and medical operations that may help interpret the existing standard. The "recommend update for standard" deliverable is used when the research results are expected to change the standard.

2.0 ORIENTATION SUMMARY OF THE RESEARCH PLAN

The IRP describes a plan of research that addresses both human physiology 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 first listed by HRP Element. Within each Element the risks are generally organized by the type of consequence: short-term health (loss of crew), mission performance (loss of mission), and long-term health. Sections 2.1 through 2.5 provide a high-level view of the research approach to the risks. Section 3.0 arranges the detailed research plans, including text and graphics, for each PRD risk. The HRP Elements are arranged in the following order:

1) Behavioral Health and Performance
2) Exploration Medical Capability
3) Human Health and 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.

2.1 BEHAVORIAL HEALTH AND PERFORMANCE (BHP)

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

2.1.1 Short-Term Health

2.1.1.1 Risk of Adverse Behavioral Conditions and Psychiatric Disorders (Short Title: Bmed)

Early detection of stress or other risk factors during spaceflight is imperative to deter development of behavioral or psychiatric conditions that could seriously harm and negatively impact 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 behavioral health during lunar and Mars 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 behavioral health and enhancing performance during long-duration isolated, confined, and highly autonomous missions and provides updates for behavioral health and performance standards.

2.1.2 Mission Performance

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

While few empirical data have been collected regarding the impact of interpersonal and intrapersonal factors on spaceflight performance, it is possible that crew conflict could jeopardize long duration exploration missions. Reports from Mir reveal that several missions may have been terminated earlier than planned due to frictions 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., Moon and Mars) where operations will require more autonomy.

BHP will 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 exploration missions.

The interviews will be used to formulate objective measures for monitoring crew cohesion and develop approaches to enhance current training and build upon the current highly successful in-flight support services and countermeasures. These measures will be tested for feasibility and acceptability in the appropriate analog environment(s). These tests will be followed by studies of ISS crew composition and crew cohesion/performance.

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 loss of capability for real-time communication, downlink, and commanding. Likewise, the crew will have to augment and adapt their schedules based on real time changes in their schedules. The extreme distance and the duration of the planned Mars mission are at the boundaries of our current knowledge. 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. BHP is collaborating with Space Medicine in a study of crew autonomy while we are still in low Earth orbit, to identify the impact (if any) of increased autonomy on crew dynamics and performance. The BHP will test conflict management approaches in ground and analog environments, and subsequently on the ISS.

2.1.2.2 Risk of Performance Errors Due to Fatigue Resulting From Sleep Loss, Circadian Desynchronization, Extended Wakefulness, and Work Overload (Short Title: Sleep)

Ground evidence clearly demonstrates that performance impairments can occur when sleep is attained in quantities similar to that attained by astronauts in flight. A correlation between sleep quantity and performance during spaceflight, however, has not been documented. BHP research aims to accurately characterize and quantify this risk by implementing studies on ISS that utilize validated measures for assessing performance relative to fatigue.

BHP research efforts further investigate contributors to sleep loss, fatigue, circadian desynchronization, and work overload, by evaluating environmental factors, individual vulnerabilities, and various aspects of mission operations. 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, preliminary studies indicate that light exposure can correct difficulties in sleep patterns that occur with shift work, jet lag and sleep disorders. Current efforts aim to investigate optimal lighting requirements for the space vehicle, as well as safe and efficacious methods for implementing lighting as a countermeasure. Other countermeasures that are currently being investigated include recommendations around sleep hygiene, optimal work-rest schedules, flight rules and requirements, and the effectiveness and safety of sleep-wake medication use in flight.

2.2 EXPLORATION MEDICAL CAPABILITY (ExMC)

2.2.1 Short-Term Health

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

To address this broad risk, the ExMC has broken it down into seven categories that correspond with the seven requirements allocated to the ExMC from the HRP PRD. Each of the seven categories is then analyzed individually to determine where gaps exist in satisfying the PRD requirements. Below are the seven categories into which the risk has been separated and an explanation of the strategy for addressing the different categories of gaps.

1.0 **Validate Standards**: The NASA Headquarters (HQ) OCHMO Standards for Crew Selection and Retention will require changes as new medical information and spaceflight technology become available. 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, through Space Medicine, will determine research needs and develop the research requirements and/or tasks necessary to fulfill this responsibility. The NASA HQ OCHMO standards that pertain to this risk are Crew Selection and Retention Criteria. The Space Medicine Medical Operations Lead for standards, working with the ExMC Element Scientist, determines gaps in knowledge in the current Crew Selection and Retention Criteria. Tasks are then identified to close those knowledge gaps.

2.0 **Quantify the Risk:** Because of the limited available operational and research data, incidence rates and outcomes for relevant medical conditions have large uncertainties associated with them. The Space Medicine Exploration Condition List is analyzed to determine gaps in our

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.

3.0 **Mitigate the Risk:** Gaps in this section deal with our knowledge about effective training and telementoring programs for exploration missions. The Space Medicine Medical Operations Lead for training, working with the ExMC Element Scientist, determines gaps in knowledge and techniques for developing future training and telementoring programs for crew, flight surgeons and biomedical ground controllers. Tasks are then identified to close those knowledge gaps.

4.0 **Monitor and Treat Each Condition:** For all Vehicle /Mission Definition and Development Programs with a Design Reference Mission (DRM), each condition on the Space Medicine Exploration Condition List is analyzed for the capabilities required to monitor and treat the condition. An analysis is performed to determine where gaps exist in current technologies and where efficiencies could be realized in the future. Based on when a technology needs to come online, a technology watch is implemented or a technology development project is initiated to deliver the technology to enable the mission.

5.0 **Provide Enabling Capabilities:** Provide data integration and management for HRP to ensure proper handling of data (e.g. Life Sciences Data Archive (LSDA), Mission Extended Medical Enterprise). Gaps exist where these capabilities are either insufficient or incomplete.

6.0 **Comply with Agency Standards:** Follow best practices and programmatic guidelines as levied by the HRP PRD. There are currently no gaps associated with this requirement.

7.0 **Reduce Resource Requirements:** Wherever possible, reduce in-flight and funding resources. There are currently no gaps associated with this requirement.

2.3 HUMAN HEALTH AND COUNTERMEASURES (HHC)

2.3.1 Short-Term Health

2.3.1.1 Risk Factor of Inadequate Nutrition (Short Title: Nutrition)

As mission duration increases, the risk of nutrient deficiencies becomes greater. Nutrient requirements, delivery requirements, and the need to preserve the nutrient content in food will increase as the frequency and duration of EVAs increase on lunar and Mars missions. Nutritional countermeasures can influence all systems.

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 and it will be decided if countermeasures need to be developed. In addition, several studies are ongoing to determine the optimal dose of vitamin D and the effects of oxidative damage.

2.3.1.2 Risk of Bone Fracture (Short Title: Fracture)

<u>Risk of Bone Fracture (Fracture) and Risk of Early Onset Osteoporosis due to Spaceflight</u> (Osteo)

These two risks are interrelated; the definition of skeletal changes due to spaceflight will inform both risks. However, some differences between the two risks are the methods for probabilistic risk

assessments, the periods (during and post mission) of risk incidence, and the approach and resources for mitigation. The combined research risk approaches are presented below.

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 a 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 represent a long-term health effect (increased osteoporosis and fracture risk) related to this discordant recovery dynamic. This information is required for assessing long-term health risks to returning crew.

While bone atrophy during spaceflight is known and requires mitigation, the time course of in-flight bone changes. Furthermore, the time course of post-flight recovery, and individual susceptibilities to multiple risk factors have not been determined. The NRAs are utilized to solicit and select proposals to gather these space normal data. In addition, work is ongoing with the Space Medicine Division to obtain risk surveillance data. In addition, the current bone standards based upon osteoporosis diagnostic guidelines are not acceptable for assessing skeletal integrity in the astronaut following prolonged spaceflight exposure. As 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 operating bands for skeletal integrity in astronauts. The long-term goals are to develop and deliver countermeasures for long-term missions, to establish the efficacy of countermeasures according to the new standards for skeletal integrity, and to monitor the combined skeletal effects of spaceflight with aging to prevent an increased lifetime health risk. 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 is the measures of 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) will improve the probabilistic assessment of fracture risk during Mars missions. 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 will drive mission operations planning.

The Risk of Bone Fracture deals with a fracture occurring during a mission up until landing on Earth. The incidence of fractures occurring after return to Earth 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 risk. The independent gaps in the Risk of Bone Fracture address fracture healing and estimating fracture risk during a mission.

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

Heart rhythm disturbances have been seen among astronauts. Most 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, some concern exists that prolonged

exposure to microgravity may lead to heart rhythm disturbances. Although this has not been observed to date, further surveillance is warranted.

Space normal must first be defined for this risk and data mining tasks are ongoing. Once the definition is determined, the data will be presented to the HSRB and it will be decided if countermeasures need to be developed.

The HRP will conduct a comprehensive study that integrates the objectives of two NRA investigations and a Supplemental Medical Objective (SMO), involving both intramural and extramural investigators. In-flight testing will require Holter monitoring, two-dimensional (2D) echocardiography, and ambulatory blood pressure monitoring. After completion of the study, the clinical expression of cardiac atrophy during long- duration spaceflight will be defined clearly, and its significance for cardiac systolic and diastolic function at rest and during gravitational transitions will be elucidated. In addition, preliminary information will be obtained regarding ventricular conduction and re-polarization that will provide either strong clinical reassurance, or pathophysiologic insight into the risk for cardiac arrhythmias. Based on the outcome of this investigation, the HRP will determine if countermeasures are necessary to prevent these conditions.

2.3.1.4 Risk of Compromised EVA Performance and Crew Health due to Inadequate EVA Suit Systems (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. Improperly designed EVA suit systems can result in the inability of the crew to accomplish planned mission objectives and can cause acute and long-term adverse impacts to crew health. Past EVA Suit 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 suit parameters, subject characteristics, and health and performance.

Mitigation of this risk will require a testing program to collect the objective data needed to make informed design decisions, which will lead to the creation of EVA systems that optimize human health and performance across the spectrum of anticipated exploration operational concepts. Multiple analogue facilities will be required due to the ability of each to simulate only certain characteristics of true micro- and partial-gravity environments.

2.3.1.5 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.

2.3.1.6 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 on Shuttle or 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.

2.3.1.7 Risk of Crew Adverse Health Event due to Altered Immune Response (Short Title: Immune)

There are no procedures currently in place to monitor immune function or its effect on crew health. Immune dysregulation has been demonstrated to occur during spaceflight, yet little in-flight immune data have been generated to assess whether or not this may be a clinical problem. Thus, HRP will conduct the “Integrated Immune SMO” to assess the clinical risks resulting from the adverse effects of spaceflight on the human immune system and will validate a flight-compatible immune monitoring strategy. The correlation between in-flight immunity, physiological stress, and a measurable clinical outcome (viral reactivation) will be determined for long- vs. short-duration spaceflight. Data from this study will be combined with the results from Shuttle-based immune studies to inform and update health

standards. Additionally, ground analogs such as NEEMO will be evaluated to determine if they represent a good analog for short-duration spaceflight. This immune dysregulation analog will be validated for some aspects of that dysregulation if it is observed in the NEEMO crews (similar to that already observed in flight crews during/following spaceflight). Data from ground studies and the Integrated Immune SMO will be assessed to determine countermeasure development needs.

2.3.1.8 Risk of Intervertebral Disc Damage (Short Title: IVD)

Evidence from medical operations indicates that astronauts have a higher incidence of intervertebral disk damage than the general population. Current studies are examining the incidence of intervertebral disc damage. Once completed, the findings will be used to guide the design of re-entry and post-flight protocols, as well as future re-entry spacecraft, as appropriate.

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

Bone is taking a Watch & Monitor mode for renal stone incidence +/- countermeasure application. Work in Nutrition Discipline is evaluating modifications to bone turnover which is a risk *factor* for renal stone formation.

2.3.1.10 Risk of Clinically Relevant Unpredicted Effects of Medication (Short Title: Pharm)

Better recordkeeping of medication use, its effectiveness, and the side effects produced should be instituted. This will provide evidence for and should be a precursor to a formal assessment of pharmacokinetics and pharmacodynamics (PK/PD) on orbit. It is believed that gastrointestinal (GI) motility and function is not an issue after the first few days of flight. In general, Space Medicine avoids prescribing oral medications during this period of the mission. It is not known to what extent different volumes of distribution might be a factor in flight. Drugs selected for the PK/PD studies should be commonly used, and have few side effects, and different metabolic pathways. External consultants should be used to determine which drugs to test and to design testing protocols. Space Medicine needs to develop a process and procedures to systematically track crew medication use, including subjective comments on efficacy and side effects, particularly for ISS. It is very important to know what pharmaceuticals are taken prior to in-flight tasks.

The overarching strategy for this risk is to obtain better record keeping of medication use, efficacy, and side effects. This includes several data mining tasks, which will provide evidence for or against this risk. If evidence indicates the ineffectiveness of medications, a PK/ PD study will be performed in flight to obtain further information.

2.3.2 Mission Performance

2.3.2.1 Risk of Impaired Control of Spacecraft, Associated Systems and Immediate Vehicle Egress 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.

2.3.2.2 Risk of Impaired Performance due to Reduced Muscle Mass, Strength and Endurance (Short Title: Muscle)

2.3.2.3 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 (2.3.2.2) and Risk of Reduced Physical Performance Capabilities due to Reduced Aerobic Capacity (2.3.2.3) are highly interrelated. Occurrence or mitigation of one risk can be a contributing factor affecting the other. Their research approaches are given together.

Human physiology's normal response to spaceflight has not been determined for these risks. Several studies have been implemented to determine how muscle and aerobic capacity are affected by microgravity; these studies include the new Integrated Resistance and Aerobic Training study, the Functional Task Test and the VO_2max study.

The Integrated Resistance and Aerobic Training study will apply principles learned from ground-based flight analogs to an in-flight platform in order to improve exercise countermeasures efficacy and efficiency by increasing exercise intensity and reducing exercise volume. Bed rest and flight data will guide the decision about efficacy of current exercise countermeasures and will determine if improved countermeasures are needed. The Functional Task Test will be implemented as a flight study as well as a bed rest study. The goal of this study is to develop and evaluate an integrated set of functional and physiological tests and then use these tests to determine how postflight changes in sensorimotor, cardiovascular, and muscle physiology impact postflight functional performance. These tests will be performed pre and postflight on astronauts exposed to short- and long-duration spaceflight. The Functional Task Test will assess operational relevance of these changes by measuring the performance of specific exploration tasks (e.g., simulated seat egress, ladder climb, hatch opening, etc.). Additionally, changes in functional performance will be mapped for standard muscular, neurological, and cardiovascular measures. Data obtained from this study will facilitate the design of countermeasures that specifically target the physiological systems responsible for impaired functional performance.

The specific aims of the VO_2max study are to measure VO_2max during and following long duration missions and to assess the validity of using submaximal measurements of heart rate (HR), and oxygen consumption (VO_2) to track changes in aerobic capacity. In addition, non-invasive measurements of cardiac output (Qc) will be performed during exercise to determine if measurement of Qc will improve the accuracy of the submaximal estimations of VO_2max. Results from this study will determine if the current countermeasures are protective and need only optimization (e.g., reduced volume, time) or if improved countermeasures and flight validation studies are needed. Due to scheduling constraints with the loss of the Mars transit analog in 2020, several concurrent studies are ongoing.

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

Twenty percent of Shuttle crewmembers and up to 83% of returning ISS crewmembers suffer hypotension and presyncope or syncope during 10 minutes of upright tilt on landing day. This may constitute a risk when crewmembers experience Earth's gravity after exposure to microgravity. Currently available countermeasures are not effective in all crewmembers; in particular, women are more susceptible to orthostatic intolerance than men are. While it is well known that crewmembers can be incapacitated by orthostatic intolerance after six-month missions when they return to Earth's gravity, the degree to which this may be ameliorated in the gravity environment on the Martian surface is not known. Early surface operations may require astronauts to be upright and active soon after landing on Mars. A combination of countermeasures, both physical and pharmaceutical, should be pursued for this risk. It is not known if exposure to 1/6 g and 3/8 g will cause orthostatic intolerance or will have mitigating effects on orthostatic intolerance upon return to 1 g. Space normal has been defined for this risk. Current research efforts are investigations to determine the efficacy of new countermeasures (i.e., Jobst stockings and pharmacological agents).

2.3.3 Long-Term Health

2.3.3.1 Risk of Early Onset Osteoporosis due to Spaceflight (Short Title: Osteo)

See section 2.3.1.2.

2.3.3.2 Risk of Spaceflight-Induced Intracranial Hypertension/Vision Alterations (SHORT TITLE: VIIP)

Some crewmembers on long duration ISS missions have experienced elevated intracranial pressure, ophthalmic anatomical changes and visual performance decrements of varying degrees and permanency. Presently these symptoms have manifested themselves as changes in eye structure such as papilledema, globe flattening, choroidal folds, cotton wool spots (CWS), increased nerve fiber layer and/or decreased near vision along with post mission spinal opening pressures ranging between 21-28.5 cm H_20 in some symptomatic astronauts. Present pre-, in-, and post-flight data indicate that after approximately 6 months of spaceflight, 15 of 36 crewmembers have shown symptoms of Spaceflight-Induced Intracranial Hypertension (SIIH). 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. In addition, a Research and Clinical Advisory Panel (RCAP) of experts was formed in December 2011 to guide current and future research and clinical activities to increase understanding of this problem.

An internal NASA team was established with Medical Operations and HRP representatives to effectively integrate tasks and progress with this risk. Medical Operations continues to approach the risk from a clinical perspective, monitoring and treating, as needed. Research will be conducted by the HRP to further quantify and mitigate the risk. The VIIP Risk research plan is in formulation, focusing on risk characterization to more clearly identify long-term health impacts as well as any potential mission performance impacts.

2.3.4 Infrastructure

The Human Health and Countermeasures Element also owns gaps related to Element infrastructure that is 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.

2.4 SPACE HUMAN FACTORS AND HABITABILITY (SHFH)

2.4.1 Short-Term Health

2.4.1.1 Risk of Adverse Health Effects due to Alterations in Host-Microorganism Interaction (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.

2.4.1.2 Risk Of Adverse Health Effects Of Exposure To Dust And Volatiles During Exploration Of Celestial Bodies (Short Title: Dust)

The toxicological effects of lunar dusts have not been studied in sufficient detail to develop an exposure standard for operations on the lunar surface. Lunar dust has properties that raise concerns for human health. Lunar dusts have a high content of respirable size particles, have large surface areas that are chemically reactive, and "nano-particles" of highly reactive elemental iron (Fe^0) are imbedded in a “rind” at the surfaces of the particles. 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 eye. NASA needs to set a permissible exposure limit (PEL) for airborne lunar dusts that is based on scientific evidence so that designs of vehicles and habitats will include features that restrain concentrations of airborne dust within safe limits. Operations must be designed to minimize the risk of abrasion to skin and eyes.

Research will evaluate and characterize factors that contribute to toxicity of the lunar dust, and then a recommendation for a PEL that accounts for these factors will be developed in collaboration with the Lunar Airborne Dust Toxicity Assessment Group (LADTAG).
Studies will determine size distributions, shape characteristics, and chemical composition of lunar particulates. Studies of the activation of lunar dust will utilize analogs of processes that activate dust on the lunar surface to reactivate lunar samples that have been passivated by exposure to air. Grinding will be used as a surrogate for micrometeorite bombardment, hydrogen and helium ion implantation will simulate the effects of solar wind, and lamps will substitute for the sun as sources of ultraviolet radiation. Understanding the processes of activation, and of passivation of reactive dust in a habitable

environment (for example, by water vapor and oxygen), are essential to assessment of the potential health effects of exposure to lunar dust and establishing appropriate limits for exposures that could occur subsequent to mission-related tasks. Activation and rates of passivation will be assessed by measuring the generation of reactive oxygen species (ROS) in solutions containing dust, and by electron paramagnetic resonance spectroscopy. Activated and passivated dusts will be tested in toxicology studies to determine the extent to which chemical activation may contribute to toxicity of the lunar dust.

Research on the unique properties of lunar dust will also advance our understanding of the mechanisms by which contact with or inhalation of lunar dust may affect human systems.

In vivo studies will include inhalation toxicity and intratracheal instillation (ITI) testing of lunar dust. Gross pathology and histopathology will be performed to gather evidence of the degree and nature of the pulmonary toxicity of lunar dust. The biochemical and cellular responses of the lung to insult by lunar dust will be determined by examination of markers of toxicity measured in bronchial alveolar lavage fluid.

Several crewmembers reported dermal and ocular issues resulting from exposure to lunar dust during the Apollo missions. Although there are anecdotal reports, there are no objective scientific data to provide a basis for estimating the extent of dermal and ocular hazards that may be present during lunar operations. Therefore, ground studies, in which simulants and authentic lunar dust will be utilized with tissue-equivalent models and animal models, will be conducted to provide a basis for estimating the extent to which acute and chronic contact with lunar dust might impair crew vision or compromise the barrier function of the skin. Data from these studies will also be made available to operations personnel and clinicians so they may be considered in the formulation of operations procedures or guidelines for treatment of injuries resulting from contact with lunar dust.

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 carbon dioxide 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 asteroids, Mars, and the moon, and minimal data on health effects of contact or airborne exposure, and the lack of a viable exposure standard, there is a possibility that exposure could lead to serious respiratory, cardiopulmonary, ocular, central nervous system, or dermal harm during lunar exploration-class missions, resulting in immediate or long-term health effects.

A first approach to address risks posed by dust and volatiles of asteroids and Mars is to study materials from those celestial bodies. For example, dust can be made by grinding meteorites that are already in the JSC curatorial facility that originated from Mars or asteroids of different types. These materials could also provide some information about volatiles as well. Health effects could be estimated by measuring chemical reactivity, response of cellular systems, and animal toxicity in studies such as those performed, or currently planned, with lunar dust. A sample return mission would add confidence that health-effects effect estimates based upon meteorite samples was representative. *In situ*, studies, perhaps using cellular systems, would provide information on the biological properties of dust once a human presence is established.

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

The Advanced Food Technology 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 nutritional content of the flight food items is not currently measured. However the retort, irradiation, and freeze-drying processes used to produce shelf stable products, reduce the nutrient content. The nutrient levels in prepared foods will be measured to ensure that they meet the requirements of nutrition 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. An integrated study investigating the combined effect of the ingredient formulation, the type of processing and packaging, and storage conditions is expected to identify optimum conditions to extend the nutrition and acceptability of the food system for longer duration missions. Methods to maintain food system acceptability and nutrition over long duration missions, including implementation of a bioregenerative 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. Methods to reduce food and packaging mass and volume overhead will be studied. These studies must overcome challenges such as storing food for extended periods (i.e., 18 months for ISS, up to 5 years for a long duration mission having pre-positioned food). Food packaging materials must be developed that minimize the mass required, while providing an adequate oxygen and moisture barrier to maintain the required shelf lives.

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2.4.2 Mission Performance

2.4.2.1 Risk of an Incompatible Vehicle/Habitat Design (Short Title: HAB)

This risk creates both short-term and long-term negative effects when a crewmember is engaged in performing a task due to problems with aspects of the designed physical working and living environment. 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 inadequate and excessive co-location of habitability related hardware and activities, difficulty donning a suit due to inadequate habitable volume, difficulties communicating with fellow crewmembers due to high levels of noise in the cabin, diminished mental capacity and discomfort due to high CO_2 levels, or short-term

disabilities caused by exposure to environmental contaminants. 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 / 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 poorly designed work practices.

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

This risk focuses on the appropriate assignment and integration of tasks among human and intelligent agents during crewed space missions. The scope of NASA's future missions will involve humans interacting with automated and robotic systems to accomplish mission goals. This will be the case for both near and deep-space exploration missions, as well as Near-Earth-Object and Planetary surface exploration. Varying classes of robotic systems (including dexterous, heavy-lift and mobility systems) will be employed for these missions. Automation will be an integral part of ground and flight systems, in addition to being utilized within Robotic systems. The level of complexity of the operations required to carry out NASA's vision will greatly increase over the paradigm of robotics and automation in use today. Human and Robot teaming will be the cornerstone of such operations. Systems will have to be designed to support multiple operators, varying time delays and increasing reliance on automation. In addition, 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. 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.

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

This risk focuses on human-computer interaction and information architecture designs that must support crew tasks, as well as how those interfaces will facilitate human performance and efficiency. Information is presented most effectively when the user's interests, needs, and knowledge are considered. 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.

2.4.2.4 Risk of Inadequate Critical Task Design (Short Title: TASK)

This risk relates to the definition and development of mission tasks, task flows, schedules, and procedures. Operations tempo is driven by the scheduling of mission tasks, and can affect 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. Tasks are driven by procedures, and when written direction, checklists, graphic depictions, tables, charts or other published guidance is inadequate, misleading or inappropriate, an unsafe situation results. Guidelines for designing task flow, schedules, and procedures are critical for ensuring task and mission success.

2.4.2.5 Risk of Performance Errors Due to Training Deficiencies (Short Title: TRAIN)

This risk focuses on the training of crew and mission support personnel, both prior to and during flight. Historically, spaceflight operations have mitigated procedure execution errors in at least two ways: specially trained crew members are assigned to missions and/or rotated into the operational environment when complex, mission-critical tasks must be performed; and, execution of such procedures is closely monitored and supported by flight controllers on the ground who have access to a broader and deeper pool of information and expertise than any individual operator. However, emerging mission architectures include long-duration operations in deep space. Such 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 (including the extent to which materials, procedures, and schedules of training should be modified).

2.5 SPACE RADIATION (SR)

Space radiation 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 know radiation effects may occur at higher dose than the extremes of the space radiation environment (e.g. acute mortality, lung toxicity, etc.) and therefore are not consider in space radiation 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 studies and provides the integrating component through development of risks assessment tools and design tools. When critical deliverables are needed such as at mission or vehicle System Requirements Review (SRR) or System Design Review (SDR), or crew selection, or for key development of operational products, the Space Radiation Program Element will serve an advisory function and technical authority, using the output of the latest independently verified and validated tools. Thus, the many deliverables will not usually map to the end of a specific study, but rather are planned to occur at the key milestones when they are needed. However, tools utilized in the design and development of vehicles will be delivered prior to Preliminary Design Review (PDR) and Critical Design Review (CDR) to be utilized during the design and analysis cycles.

2.5.1 Long-Term Health

2.5.1.1 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 if needed. 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 DOE Low Dose Research Program is a key component of the strategy. The DOE program focus is on low Linear Energy Transfer (LET) irradiation; collaborative grants are also being selected from proposals that contain one or more Specific Aims addressing NASA interests using the NSRL. This research augments SR research with a large number of grants that use state-of-the art approaches, i.e., genetics, proteomics, and transgenic animal models, etc. The DOE research is an important part of the goal to identify biomarkers of cancer risk.

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. Research in this area is a major focus of studies at NSRL. For some cancer sites and exposure conditions, for 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.

2.5.1.2 Risk of Acute 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. Central nervous system (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.

2.5.1.3 Risk of Degenerative Tissue or other Health 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, wherein the Union is supporting large-scale mouse studies of CHD. 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.

Cataracts have long been a research focus of the SR. An increased risk of cataracts associated with low-dose space radiation has been reported from past NASA missions, and is being followed up with a clinical study of cataract progression rates in current or retired astronauts. Several NSRL studies of risks are supported to improve the understanding of how protons and HZE nuclei induce cataracts, and to identify possible countermeasure approaches. As well, SR continues to support studies to improve the understanding of how protons and HZE nuclei induce cataracts and to identify possible countermeasure approaches.

2.5.2 Short-Term Health

2.5.2.1 Risk of Acute Radiation Syndromes due to Solar Particle Events (Short Title: ARS)

A variety of acute radiation syndromes are of concern following a 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 a SPE leading to burns, or other 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 space radiation.

3.0 DESCRIPTION OF HRP ELEMENTS CONTENT LOCATED IN THE HUMAN RESEARCH ROADMAP

The format for the Elements' inputs includes graphical depiction via Gantt charts and written discourse to clarify the Elements' approach. Each input follows the same form. Each risk in the purview of that

Element is reported, along with its criticality to the Lunar Outpost mission the Near Earth Asteroid mission, and the Mars mission; the operational relevance is described; the strategy for mitigation is given; the gaps in knowledge are reported with a brief description; and the activity or activities necessary to address the gap are described. For each activity, the resulting product/deliverable, the required delivery milestone for the deliverable, the required platform, and the Portfolio/Project or organization responsible for implementing the activity are all defined.

3.1 RISKS

Each HRR text description has a statement of the risk. These statements are verbatim from the PRD, and are reprinted in the IRP as a matter of convenience for the reader. With the title of each risk, the criticality is given. Criticality ratings correspond to the criteria given in Section 1.4.1 of this document.

3.2 CONTEXT

This section provides the context of how the research plan is built for that risk and describes the need for the research at a very high level.

3.3 OPERATIONAL RELEVANCE

In this paragraph, a description of the relevance to the exploration mission is given.

3.4 STRATEGY FOR MITIGATION

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.

3.5 GAPS

Gaps in our knowledge or in the evidence base exist for each risk. These gaps have several different forms. A gap may exist in our evidence base, which leaves greater uncertainty regarding the likelihood of the risk. A gap may exist in the identification of the appropriate countermeasure. For other risks, the gap may be in the flight validation of the appropriate countermeasure. For the purposes of this IRP, the gaps are not delineated by type; rather they are simply identified as gaps that must be filled before the risk is mitigated. In some cases, a gap may not require research to close it; the gap can be avoided altogether through selection of a specific vehicle or mission design.

3.6 TASKS

For each gap, the task(s) required to fill that gap are listed. Each task is named and a short description is given. In some cases, a task can address multiple gaps within a risk or across multiple risks. In addition, the Element responsible for implementation of the task is listed, along with the anticipated procurement method. In some cases, the organization performing the task is not within the Element responsible for the risk; this entity will be listed as a Supporting Organization. The responsible Element will coordinate with the appropriate organization in those cases.

3.7 DELIVERABLES

A deliverable is an end product(s) to which the customer and supplier have agreed. The supplier is the primary provider of the deliverable(s). The customer is the primary recipient that takes ownership of the deliverable(s). A stakeholder is an entity with interest in deliverable(s).

Each task or progression of tasks is designed to ultimately culminate in a deliverable to a Vehicle or Mission Definition & Development Program, the OCHMO, or the Mission Operations Directorate. Deliverables to these entities often affect mission planning or impose mission operations scheduling, constraints such as a new flight rule for sleep schedules or exercise timelines.

A deliverable from an individual task often fills a gap in some other HRP Element. Part of the IRP maturation process is to identify critical dependencies for each gap. These critical dependencies will include, in some cases, information developed under another gap. The need dates for these deliverables are determined by when the other Element needs the information.

The deliverable categories are listed in the table below and briefly described in the text that follows.

Table 3.7 Category Options for Deliverables

Category	Subcategory	Example Customers	Example Deliverables
Requirements	Vehicle/Suit Design	Vehicle/Mission Definition & Development Programs	Suit Design Requirements
	Flight Rule/ MRID/Practice Guidelines	Medical/Mission Operations	Questionnaires, Procedures
Technology	Systems Solutions, Prototype H/W	Medical Operations , Vehicle/ Mission Definition & Development Programs	Food Packaging Technologies, In-flight Blood Analysis Technology
	Clinical Care, Medical Informatics	Medical Operations	Training Protocol for Effective Medical Operations
Tools	Computational Models, Software	Medical Operations, OCHMO, Vehicle/Mission Definition & Development Programs	Radiation Risk Assessment Models, Digital Astronaut
	Database	Human Research Program	Database created by gathering existing data, New database created for data input
	Simulation	Medical Operations, Vehicle Mission Definition & Development Programs	IMM Decision Support Tool
Countermeasures	Prescription	Medical Operations, OCHMO	Integrated Resistance and Aerobic Training Study
	Protocol	Medical Operations, OCHMO	Consumables Tracking System, Prebreathe Protocol

			for Exploration Scenarios
	Prototype H/W, Pharmaceutical/ Nutritional Supplement	Medical Operations, OCHMO, Vehicle/Mission Definition & Development Programs	Pharmaceutical recommendations resulting from Vitamin D Study
Standards	Update	OCHMO	Nutrition Standard Update
	New	OCHMO	Lunar Dust PEL
Risk Characterization, Quantification	Evidence	OCHMO	NRA Final Report RMAT Evidence Report Conceptual model
Study	Customer Requested Study or Analysis	Vehicle/Mission Definition & Development Programs	Trade Study Analysis Results and Recommendations

Requirements

The "Requirements" deliverable is chosen when a task will result in information that is relevant to a requirement (or requirements set) 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 (see section 3.13).

Technology

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

Tool

A "Tool" deliverable can encompass design tools, software, databases, computational models or systems simulations.

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 pharmaceuticals, devices, 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 (see section 3.13).

Standards

A "Standards" 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 "Standards" deliverables to result in a recommendation for a new or updated standard.

A "Standards" 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 shown in the blue section at the top of the Gantt chart in Appendix A. 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 (see section 3.13 this document).

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

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 as defined in 1.4.2 typically produce this type of deliverable.

3.8 REQUIRED DELIVERY MILESTONE

Key milestones within Vehicle or Mission Definition and Development Programs, or Medical or Mission Operations drive the required date for the HRP deliverables. For instance, design requirements typically must be defined by the appropriate SRR. Design solutions and technology typically must be defined to a Technology Readiness Level (TRL) 6 by the Preliminary Design Review. TRLs are defined in Appendix B. This section documents the schedule drivers for the delivery milestones.

3.9 REQUIRED PLATFORMS

This section defines the platform required to perform the research. Platforms can be designated as ground analog environments, such as NEEMO, or Antarctica; or the platform may be a space-based one, such as the ISS. Also, the lunar surface is a platform that is anticipated in some research efforts. If the ISS or ground analogs are required, a summary of the following resource requirements is given: number of subjects, initial upmass, upmass/subject, downmass, crew time per subject, and post-flight baseline data collection time.

3.10 ORGANIZATION RESPONSIBLE FOR THE IMPLEMENTATION OF ACTIVITY

The HRP Elements are responsible for implementation of the Element research plan. In some cases, organizations outside the Element, such as other HRP Elements, other divisions within NASA, the NSBRI, or even an international partner, are responsible for implementation of specific tasks in the research plan. These supporting organizations are identified within this section.

For each task the organization with primary responsibility for its implementation is listed. In some cases, the organization is not within the Element responsible for the risk that the task informs. The Element responsible will coordinate with the appropriate organization in those cases.

Discipline teams include the participation of operations personnel, the NASA research discipline experts, and the National Space Biomedical Research Institute (NSBRI). In several cases, the primary responsibility is shown as that of NASA; however, that does not mean that the NSBRI is not participating at all. The NSBRI participates through the discipline teams, as well as through future solicitations.

3.11 GRAPHIC INPUT

Section 4.0 contains an example of a Gantt chart legend and chart for an example risk, with each section of the chart labeled. Each Gantt chart graphic is supported with text that provides a more thorough level of detail. There is one set of Gantt charts for each of the 32 PRD risks. The Element to which the risk is allocated is identified in the upper left corner. The research gaps are identified by name and number along the left side for each risk. Under each gap are the identified tasks required to fill the gap. Each task is identified by full or short title. The activities are bar-coded per the legend given. The schedule of each task is shown on the graphic and an arrow shows deliverables resulting from the activity. The deliverable may relate to the schedule at the top of the chart.

3.12 DECISION POINTS

Several key decision points have been placed in the plan. At these key decision points, the appropriate forward path for the research will be reevaluated. The decision points are cast in a “Yes/No” form, and it is anticipated that at these points, the responsible Element will review the current state of the evidence, and review the appropriate approach to the forward plan. Where applicable, the Science Management Office will concur and, if necessary, the appropriate Standing Review Panel may be convened to deliberate and make recommendations. Criteria for making the decision will be determined on a case-by-case basis and will be consistent with the overall management structure documented in the Science Management Plan.

3.13 HARDWARE DEVELOPMENT CYCLE

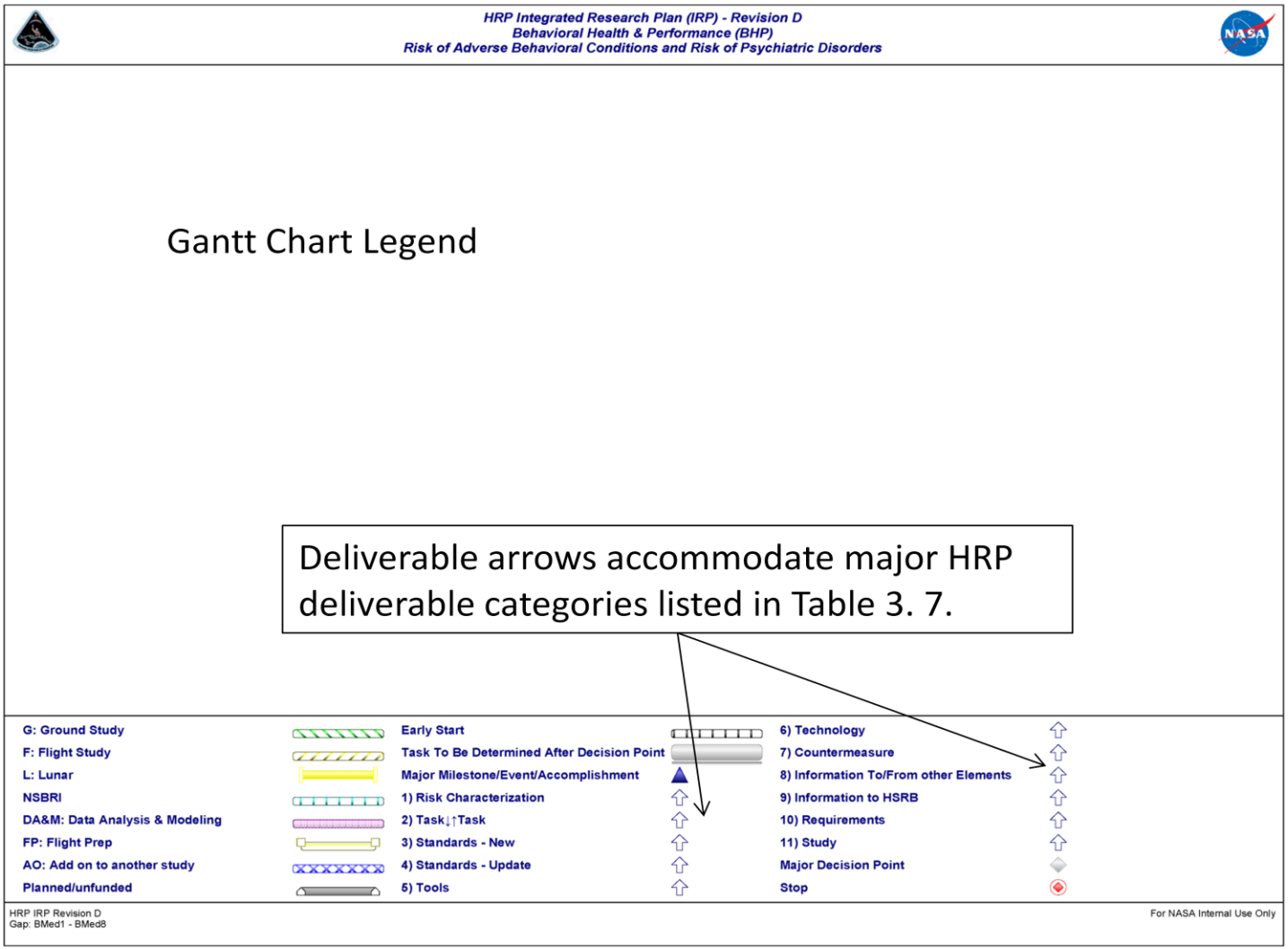
Many HRP deliverables contribute to hardware development. A NASA hardware development proceeds through several stages, with reviews occurring between the stages. The exploration program goes through these stages as it designs the next crew capsule, a lunar lander, and the next generation space suit.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

- 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 Change Request 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.

4.0 GANTT CHARTS


HRP Integrated Research Plan (IRP) - Revision D
Behavioral Health & Performance (BHP)
Risk of Adverse Behavioral Conditions and Risk of Psychiatric Disorders
Gantt Chart Legend
Deliverable arrows accommodate major HRP deliverable categories listed in Table 3. 7.
G: Ground Study
F: Flight Study
L: Lunar
NSBRI
DA&M: Data Analysis & Modeling
FP: Flight Prep
AO: Add on to another study
Planned/unfunded
Early Start
Task To Be Determined After Decision Point
Major Milestone/Event/Accomplishment
1) Risk Characterization
2) Task↓↑Task
3) Standards - New
4) Standards - Update
5) Tools
6) Technology
7) Countermeasure
8) Information To/From other Elements
9) Information to HSRB
10) Requirements
11) Study
Major Decision Point
Stop
HRP IRP Revision D
Gap: BMed1 - BMed8
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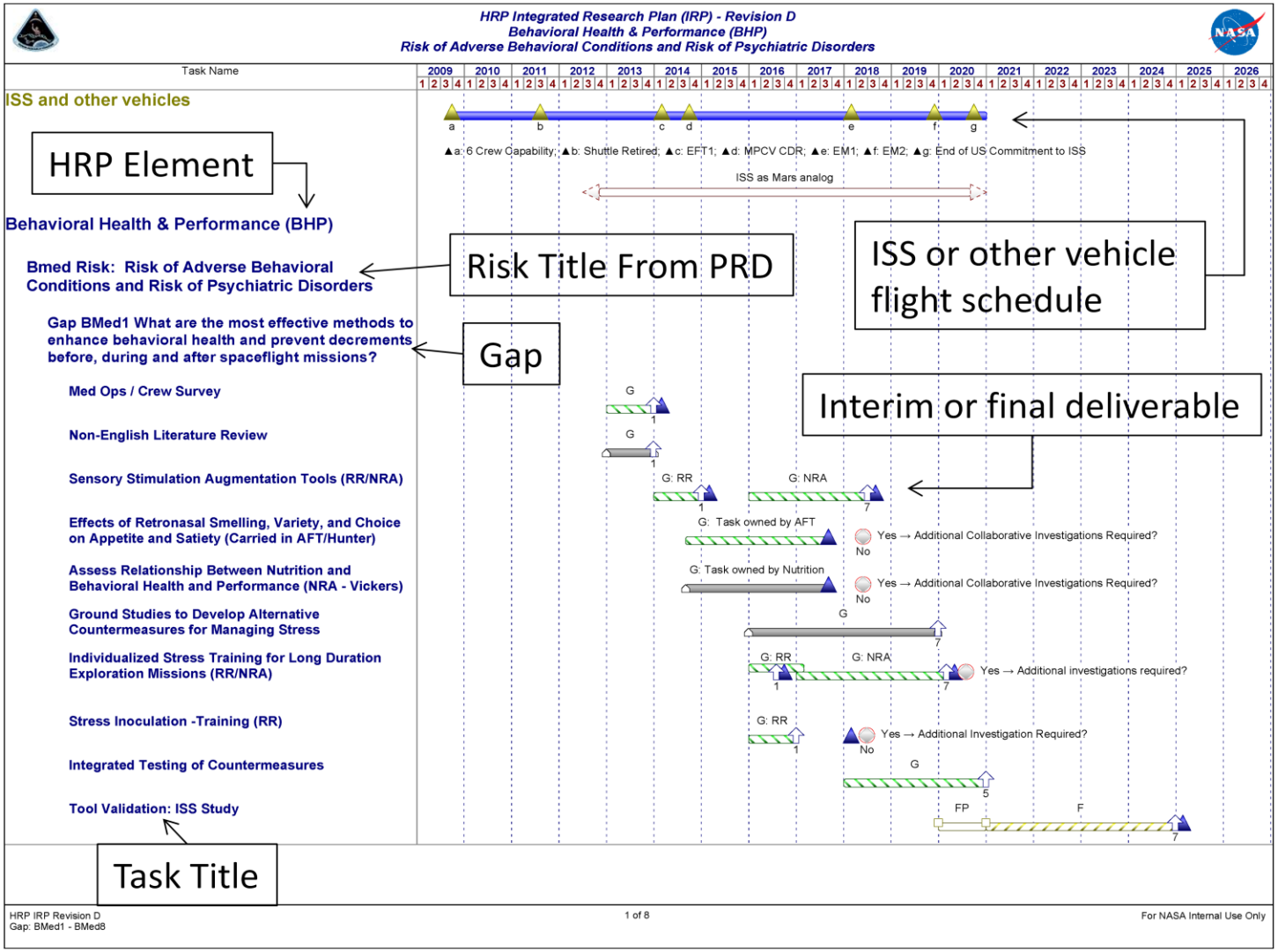
HRP Integrated Research Plan (IRP) - Revision D
Behavioral Health & Performance (BHP)
Risk of Adverse Behavioral Conditions and Risk of Psychiatric Disorders
Task Name
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026
ISS and other vehicles
a b c d e f g
▲a: 6 Crew Capability; ▲b: Shuttle Retired; ▲c: EFT1; ▲d: MPCV CDR; ▲e: EM1; ▲f: EM2; ▲g: End of US Commitment to ISS
ISS as Mars analog
HRP Element
Behavioral Health & Performance (BHP)
Bmed Risk: Risk of Adverse Behavioral Conditions and Risk of Psychiatric Disorders
Risk Title From PRD
ISS or other vehicle flight schedule
Gap BMed1 What are the most effective methods to enhance behavioral health and prevent decrements before, during and after spaceflight missions?
Gap
Interim or final deliverable
Med Ops / Crew Survey
Non-English Literature Review
Sensory Stimulation Augmentation Tools (RR/NRA)
G: RR
G: NRA
Effects of Retronasal Smelling, Variety, and Choice on Appetite and Satiety (Carried in AFT/Hunter)
G: Task owned by AFT
Yes → Additional Collaborative Investigations Required?
No
Assess Relationship Between Nutrition and Behavioral Health and Performance (NRA - Vickers)
G: Task owned by Nutrition
Ground Studies to Develop Alternative Countermeasures for Managing Stress
Individualized Stress Training for Long Duration Exploration Missions (RR/NRA)
Yes → Additional investigations required?
Stress Inoculation -Training (RR)
Yes → Additional Investigation Required?
Integrated Testing of Countermeasures
Tool Validation: ISS Study
FP
F
Task Title
HRP IRP Revision D
Gap: BMed1 - BMed8
1 of 8
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APPENDIX A- LINK TO HUMAN RESEARCH ROADMAP

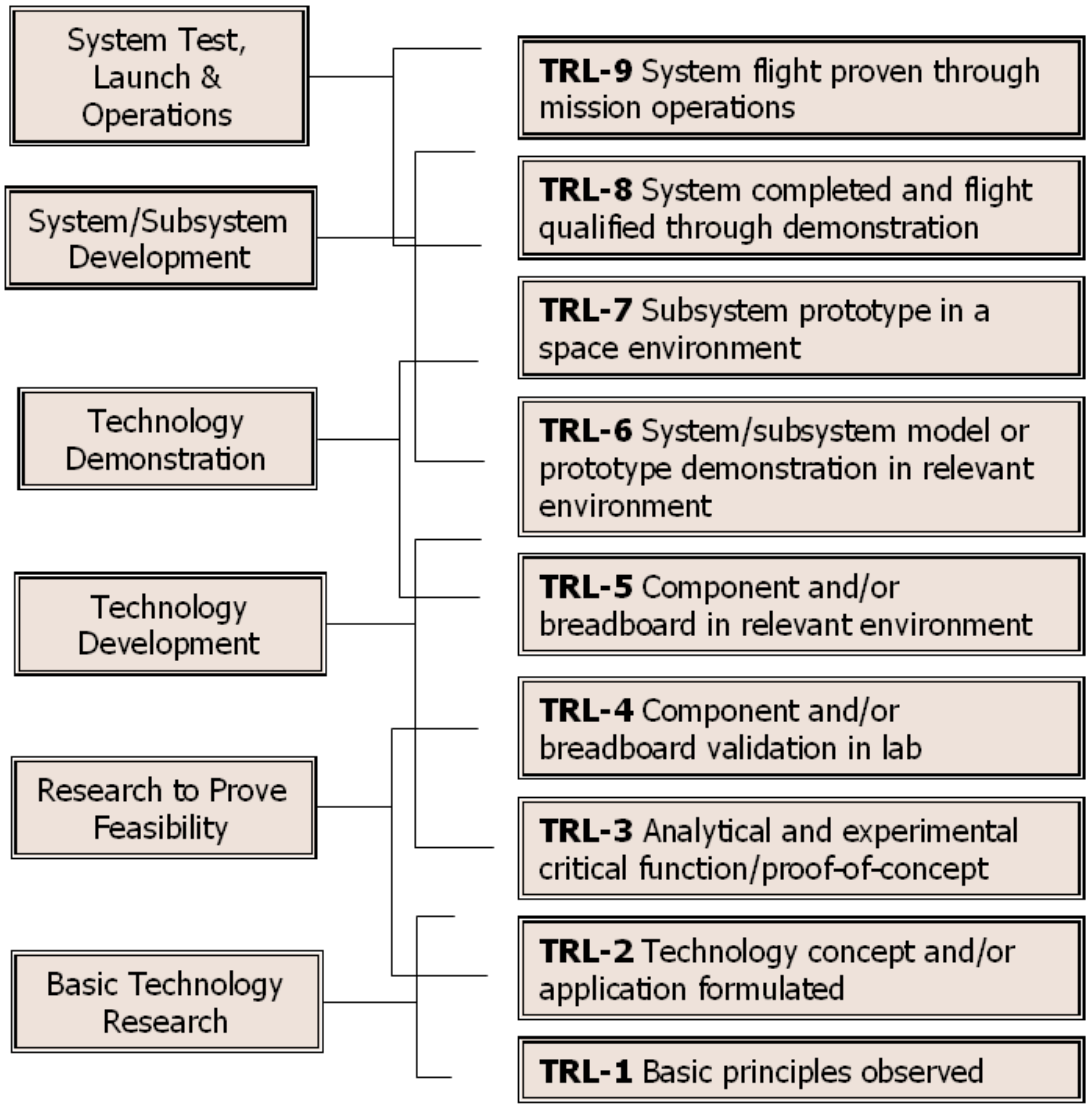
Risk, gap and task information that was formerly contained in Appendix A is now located in the HRR:

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)

Definition of Technology Readiness Levels (TRL)



Appendix C - **LIST OF ACRONYMS**

A

AEH	Advanced Environmental Health
AFT	Advanced Food Technology

B

BEO	Beyond low earth orbit
BHP	Behavioral Health and Performance

C

CDR	Critical Design Review
CNS	Central Nervous System
CO_2	Carbon Dioxide
CR	Change Request
CWS	Cotton Wool Spots

D

DA	Digital Astronaut
DCS	Decompression Sickness
DOE	Department of Energy
DRM	Design Reference Mission

E

EVA	Extravehicular Activity
ExMC	Exploration Medical Capability

F

FAP	Flight Analogs Project

G

g	Gravity
GCR	Galactic Cosmic Rays
GI	Gastrointestinal

H

HEOMD	Human Exploration and Operations Mission Directorate
HHC	Human Health Countermeasures
HIDH	Human Integration Design Handbook
HQ	Head Quarters
HRP	Human Research Program
HRR	Human Research Roadmap
HSRB	Human Systems Risk Board
HZE	High Charge and Energy

I

IOM	Institute of Medicine
IRP	Integrated Research Plan
ISS	International Space Station

ISSMP	International Space Station Medical Projects

J

JSC	Johnson Space Center

K

L

LADTAG	Lunar Airborne Dust Toxicity Assessment Group
LET	Linear Energy Transfer
LOC	Loss of Crew
LOM	Loss of Mission

M

MLD	Master Logic Diagram
MRID	Medical Requirements Integration Document

N

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

O

O_2	Oxygen
OCHMO	Office of the Chief Health and Medical Officer

P

PCA	Program Commitment Agreement
PD	Pharmacodynamics
PDR	Preliminary Design Review
PEL	Permissible Exposure Limits
PK	Pharmacokinetics
PRD	Program Requirements Document

Q

Qc	Cardiac Output

R

RCAP	Research and Clinical Advisory Panel
REV.	Revision
RFP	Request for Proposal

RID	Review Item Discrepancy
RMAT	Risk Management Analysis Tool
ROS	Reactive Oxygen Species

S

SAR	System Acceptance Review
SBIR	Small Business Innovation Research
SDR	System Design Review
SHFE	Space Human Factors Engineering
SHFH	Space Human Factors and Habitability
SIIH	Spaceflight-Induced Intracranial Hypertension
SMO	Supplemental Medical Objective
SOMD	Space Operations Mission Directorate
SPE	Solar Particle Event
SR	Space Radiation
SRR	System Requirements Review
STD	Standard

T

TBD	To Be Determined
TRL	Technical Readiness Level

U

V

VO_2max	Maximal oxygen consumption

WXYZ