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Volume 1, Revision C

National Aeronautics and Space Administration

Office of the Chief Health and Medical Officer
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Volume 1, Revision B

NASA SPACEFLIGHT HUMAN-SYSTEM STANDARD

VOLUME 1: CREW HEALTH

DOCUMENT HISTORY LOG

Status	Document Revision	Change Number	Approval Date	Description
Baseline			2007-03-05	Initial Release
Revision	A		2014-07-30	This is a complete revision with the following major changes: Radiation (Requirement Updates) Decompression Sickness (New Standard) Aerobic Capacity (Requirement Updates) Orthostatic Hypotension (New Requirement)
Change		1	2015-02-12	Administrative Change: Corrected two typos on page 22 in Table 1: 1. Last row column 3 from: 1,00 to 100 2. Last row column 4 from: 2,50 to 250 These edits provide the correct values and return the listed limits to what appeared in the baseline version of NASA-STD-3001. Corrected two typos on page 76 in Table 7: 1. Title from (mSv to Sv) Row 3, column 3, from 0.06 Sv to 0.6 Sv.
Revision	B		2022-01-05	This is a complete revision with the following major changes: Section 3 -The Levels of Care have been replaced with Health and Medical Care Technical requirements. Section 4 - Aerobic Capacity Requirements to account for celestial surface conditions during EVAs. Updates to Bone Mineral Density Technical requirements to reflect new evidence. Updates to Bone Mineral Density Technical requirements to reflect new evidence Updates and additions to the Radiation Technical requirements, including a new technical requirement addressing Crew Radiation Limits for Nuclear technologies. Many Technical requirements have been deleted as their information has been captured in the New Health and Medical Care Technical requirements section (section 3). A new PRA appendix has been added clarifying the process of medical conditions screening and treatment development.

Status	Document Revision	Change Number	Approval Date	Description
Revision	C		2023-09-13	Editorial changes throughout document with the following sections/technical requirements that were materially changed either in the text of this NASA Technical Standard and/or in the rationale: Section 1, Section 2, 3.1/[V1 3000] 3.3/[V1 3002], 3.4/[V1 3003], 3..5/[V1 3004], 3.6/[V1 3007], 3.7/[V1 3008], 3.9/[V1 3010], 3.11/[V1 3012], 3.12.1/[V1 3013], 3.12.2/[V1 3014], 3.13/[V1 3015], 3.1.14/[V1 3016], 3.1.15/[V1 3017], 3.1.16/[V1 3018], 4.1 Intro, 4.1.1/[V1 4001], 4.1.2/[V1 4002], 4.1.3/[V1 4003], 4.1.4/[V1 4004], 4.2 Intro, 4.2.1/[V1 4005], 4.3 Intro, 4.4.1/[V1 4015], 4.4.3/[V1 4017], 4.3.2/[V1 4012], 4.3.4/[V1 4014], 4.4 Intro, 4.4.3/[V1 4017], 4.5 Intro, 4.5.1/[V1 4019], 4.5.2[V1 4020], 4.6 Intro, 4.6.1/[V1 4023], 4.6.2/[V1 4024], 4.6.3/[V1 4025], 4.7 Intro, 4.7.2[V1 4027], 4.8.2/[V1 4030], 4.8.3/[V1 4031], 4.8.4/[V1 4032], 5 Intro, 5.1/[V1 5001], 5.2/[V1 5002], 5.2.1/[V1 5003], 5.2.2/[V1 5004], 5.3/[V1 5005], 5.4/[V1 5006], 5.5/[V1 5007], 5.6/[V1 5008], 5.7/[V1 5009], 6.1/[V1 6001], 6.2.1/[V1 6002], 6.2.2/[V1 6003], 6.3.1/[V1 6004], 6.3.2/[V1 6005], 6.4/[V1 6006],6.5.1/[V1 6008], 6.5.2/[V1 6009], 7 Intro, 7.1/[V1 7001], 7.2/[V1 7002], 7.3/[V1 7003], Appendices A-E. Deletion of the following sections/technical requirements: 3.1.6/[V1 3005], 3.1.6.1/[V1 3006], 3.1.10/[V1 3011], 4.5.3/[V1 4021], 6.3.2/[V1 6005], 6.5/[V1 6007] The following sections/technical requirements were added throughout this NASA Technical Standard: 3.1.10.1/[V1 3050], 3.1.10.2/[V1 3051, 3.1.10.3/[V1 3052], 3.1.10.4/[V1 3053], 3.1.10.5/[V1 3054], 3.1.10.6/[V1 3055], 3.1.10.7/[V1 3056], 4.8.5[V1 4033], 6.3.2.1/[V1 6010], 6.3.2.2/[V1 6011]

FOREWORD

This NASA Technical Standard is published by the National Aeronautics and Space Administration (NASA) to provide uniform engineering and technical requirements for processes, procedures, practices, and methods endorsed as standard for NASA programs and projects, including technical requirements for selection, application, and design criteria of an item. This NASA Technical Standard provides uniform technical requirements for the design, selection, and application of hardware, software, processes, procedures, practices, and methods for human-rated systems.

This NASA Technical Standard is approved for use by NASA Headquarters and NASA Centers and Facilities, including Component Facilities and Technical and Service Support Centers, and applicable technical requirements may be cited in contract, program, and other Agency documents. It may also apply to the Jet Propulsion Laboratory (A Federally Funded Research and Development Center [FFRDC]), other contractors, recipients of grants and cooperative agreements, and parties to other agreements only to the extent specified or referenced in applicable contracts, grants, and agreements.

This NASA Technical Standard establishes Agency-wide technical requirements that minimize health and performance risks for flight crew in human spaceflight programs. This NASA Technical Standard applies to space vehicles, habitats, facilities, payloads, and related equipment with which the crew interfaces during spaceflight and lunar and planetary, e.g., Mars, habitation.

In this NASA Technical Standard, the Office of the Chief Health and Medical Officer establishes NASA's spaceflight crew health technical requirements for the pre-mission, in-mission, and post-mission phases of human spaceflight. These technical requirements apply to all NASA human spaceflight programs and are not developed for any specific program.

Requests for information should be submitted via "Feedback" at https://standards.nasa.gov. Requests for changes to this NASA Technical Standard should be submitted via MSFC Form 4657, Change Request for a NASA Engineering Standard.

15 Sept 2023

J.D. Polk, DO, EdD, MMM, CPE, FACOEP, FAsMA, FEWM
NASA Chief Health and Medical Officer
NASA Headquarters

Approval Date

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1. SCOPE

The scope of this NASA Technical Standard is restricted to human spaceflight missions and includes activities affecting crew in all phases of the life cycle (design, development, test, operations, maintenance), both inside and outside the spacecraft, while on Earth, in space, and on extraterrestrial surfaces.

1.1 Purpose

The purpose of this NASA Technical Standard is to provide uniform technical requirements for crew health, performance, training, medical operations, design, selection, and application of hardware, software, processes, procedures, practices, and methods for human-rated systems. This technical standard has been established to guide and focus the development of the crew health technical requirements as a means of protecting spacefaring crews. NASA-STD-3001, Spaceflight Human-System Standard, is a two-volume set of NASA Agency-level technical requirements established by the Office of the Chief Health and Medical Officer (OCHMO), directed at minimizing health and performance risks for flight crews in human spaceflight programs.

NASA's policy for establishing technical requirements to protect the health and safety of crew and for providing health and medical programs for crewmembers during all phases of spaceflight is authorized by NPD 1000.3, The NASA Organization, and NPD 8900.5, NASA Health and Medical Policy for Human Space Exploration. NPD 8900.1, Medical Operations Responsibilities in Support of Human Space Flight Programs, and NPD 8900.3, Astronaut Medical and Dental Observation Study and Care Program, authorize the specific provision of health and medical programs for crewmembers. NASA's policy is to establish technical requirements for providing a healthy and safe environment for crewmembers and to provide health and medical programs for crewmembers during all phases of spaceflight. Technical requirements are established to maintain crew health and performance, contributing to overall mission success and preventing negative long-term health consequences related to spaceflight. In this NASA Technical Standard, the OCHMO establishes NASA's spaceflight crew health technical requirements for the pre-mission, in-mission, and post-mission phases of human spaceflight.

All technical requirements are based on the best available scientific and clinical evidence, as well as operational experience from Gemini, Apollo, Skylab, Shuttle, Shuttle/Mir (Russian space station), International Space Station (ISS) missions and Commercial Crew Program (CCP). Technical requirements are periodically and regularly reviewed, especially as the concept of operations and mission parameters for a program become defined and may be updated as new evidence emerges.

NASA-STD-3001, Volume 1: Crew Health, sets technical requirements for fitness for duty, spaceflight permissible exposure limits (PEL), permissible outcome limits (POL), health and medical care, medical diagnosis, intervention, treatment and care, and countermeasures. This volume considers human physiologic parameters as a system, much as one views the engineering and design of a mechanical device. Doing so allows the human-system to be viewed as an integral part of the overall vehicle design process, as well as the mission reference design, treating the human-system as one system along with the many other systems that work in concert to allow the nominal operation of a vehicle and successful completion of a mission.

The technical requirements presented in this volume of the NASA Technical Standard are intended to complement the overall set of human technical requirements for spaceflight, which also includes NASA-STD-3001, Volume 2: Human Factors, Habitability and Environmental Health; OCHMO-STD-100.1A, NASA Astronaut Medical Standards Selection and Annual Recertification; and current medical standards of clinical practice.

NASA-STD-3001, Volume 2: Human Factors, Habitability, and Environmental Health sets technical standards for human system integration, human physical and cognitive capabilities and limitations, and spacecraft (including orbiters, surface vehicles, habitats, and suits) internal environments, habitability, architecture and hardware and equipment. It also includes technical requirements for ground processing, facilities, payloads, and related equipment, hardware, and software systems with which the crew interfaces during space operations. This volume considers human-system integration where the context is about how the human crew interacts with other systems, including the habitat and the environment. The focus is on performance issues during a mission—whether the human and the system can function together (within the environment and habitat) and accomplish the tasks necessary for mission success.

Combined, these volumes provide Agency technical requirements for an appropriate environment for human habitation, certification of human participants, the necessary level of medical care, and risk-mitigation strategies against the deleterious effects of spaceflight. These technical requirements help ensure mission completion, limit morbidity, and reduce the risk of mortality during spaceflight missions.

NASA/SP-2010-3407, Human Integration Design Handbook (HIDH) is a compendium of human spaceflight history and knowledge and serves as resource for implementing NASA-STD-3001 by providing the background, data, and guidance necessary to derive and implement program- and project-specific requirements that in are in compliance with NASA-STD-3001. It is organized in the same sequence as NASA-STD-3001, Volume 2, and provides useful background information and research findings. The HIDH is also meant to help program planners, designers, and human factors and health practitioners achieve a successful integration of humans and systems. A complementary reference document to the HIDH is NASA/TP-2014-218556, Human Integration Design Processes (HIDP). The HIDP describes the "how-to" processes, including methodologies and best practices that NASA has used during the development of crewed space systems and operations. Additional supplementary resource information can be found on the OCHMO Human Spaceflight and Aviation Standards webpage (https://www.nasa.gov/ochmo/health-operations-and-oversight/hsa-standards/).

1.2 Applicability

This NASA Technical Standard is applicable to human space systems. The technical requirements specified in this volume:

a. Apply to all space exploration programs and activities involving crewmembers.

b. Apply to internationally provided space systems as documented in distinct separate agreements such as joint or multilateral agreements.

c. Are to be made applicable to contractors only through contract clauses, specifications, or statements of work in conformance with the NASA Federal Acquisition Regulation (FAR) supplement and not as direct instructions to contractors.

NPR 8705.2, Human-Rating Requirements for Space Systems, defines the requirements for space systems. HEOMD-003, Crewed Deep Space Systems Human Rating Certification Requirements and Standards for NASA Missions is a tailoring of NPR 8705.2 for crewed deep space systems. The intent of this NASA Technical Standard is to be the foundation for the program/project requirements and verification documentation.

This NASA Technical Standard is approved for use by NASA Headquarters and NASA Centers and Facilities, and applicable technical requirements may be cited in contract, program, and other Agency documents. It may also apply to the Jet Propulsion Laboratory (a Federally Funded Research and Development Center [FFRDC]), other contractors, recipients of grants and cooperative agreements, and parties to other agreements only to the extent specified or referenced in their contracts, grants, or agreements.

This NASA Technical Standard applies to all internationally provided space systems only if required and documented in distinct separate agreements such as joint or multilateral agreements.

The NASA Technical Authorities—Health and Medical Technical Authority (HMTA), Engineering Technical Authority (ETA), and Safety and Mission Assurance Technical Authority (SMA TA)—assess NASA programs and projects for compliance with NASA-STD-3001. If the program or project does not meet the provisions of this NASA Technical Standard, then the associated risk to the health, safety, and performance of the crew is evaluated by the Technical Authorities.

Verifiable technical requirement statements are designated by the acronym of the volume (e.g., "[V1]" for Volume 1), numbered, and indicated by the word "**shall**." Explanatory or guidance text is indicated in italics beginning in Section 3, Health and Medical Care. To facilitate technical requirements selection by NASA programs and projects, a Requirements Compliance Matrix is provided in Appendix D, D.2-1.

1.2.1 Program/Project Implementation

Applicability of individual technical requirements may change based on individual program/project parameters and must be considered to ensure cost-effective implementation of this NASA Technical Standard. Therefore, all technical requirements in this NASA Technical Standard are applicable to all NASA human spaceflight programs/missions/projects unless determined otherwise and agreed to by the delegated Technical Authority based on the following criteria:

a. Gravitational Environment,

b. Full Mission Duration ,
c. Time to receive terrestrial medical capability,
d. Radiation Environment,
e. Spacesuit Capability,
f. Destination,
g. Mission Phase, or
h. Other definable mission parameter.

As per NPR 7120.5, NASA Space Flight Program and Project Management Technical Requirements, during the systems requirements phase of program or project development, technical requirements applicability will be determined based on the program's mission parameters. Refer to Figure 1.2-1—Applicability, Tailoring, and Verification of Requirements for Human Space Flight Programs/Projects, for the process of applicability, tailoring, and verification of requirements for programs or projects.

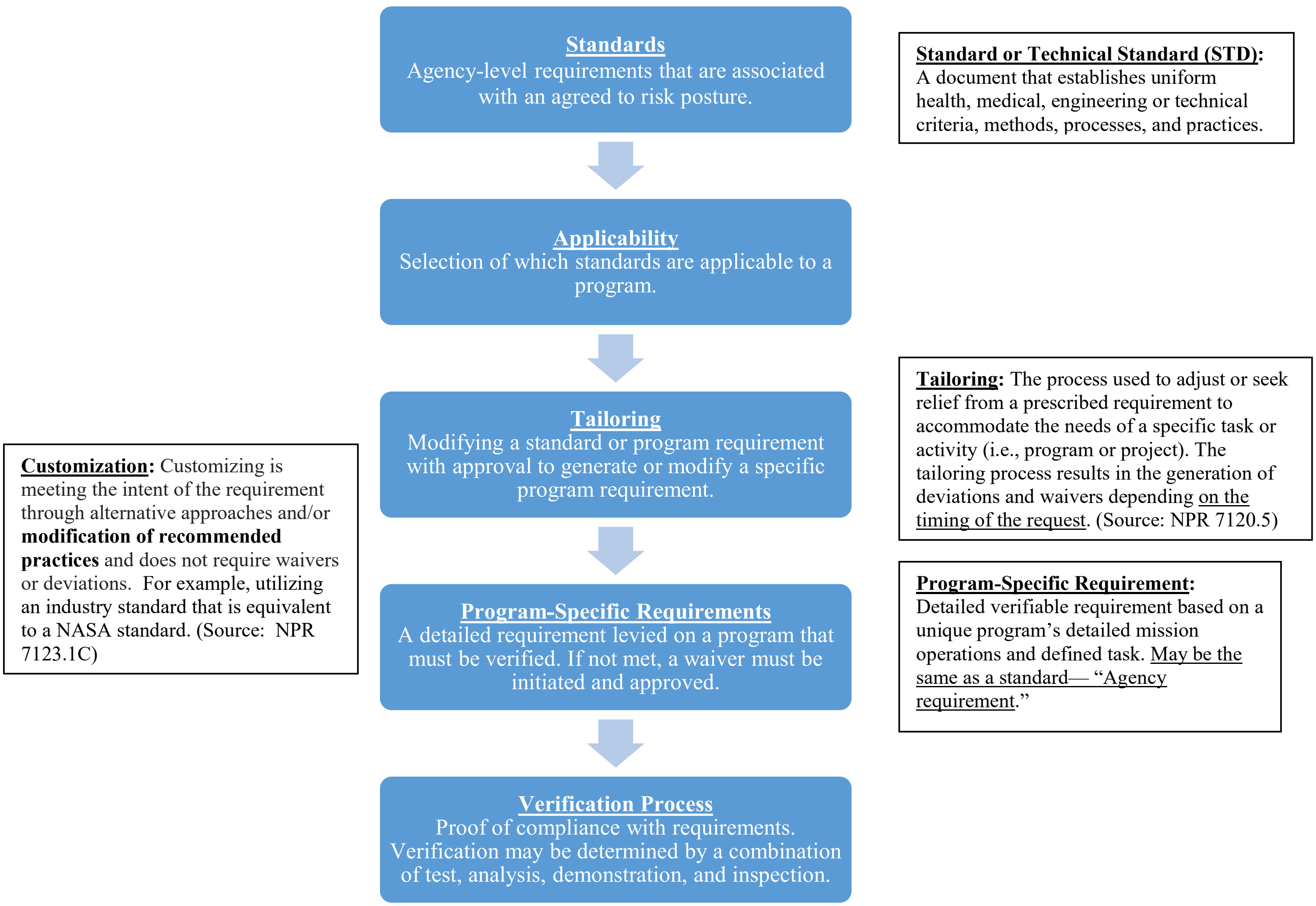

Figure 1.2-1—Applicability, Tailoring, and Verification of Technical Requirements for Human Space Flight Programs/Projects

1.2.2 Full Mission Duration Applicability

In order to protect human health and performance from exposures or conditions that have a cumulative effect, technical requirements will be tailored into program requirements pertaining to the full mission duration (from launch of crew through their landing back on Earth) for each human spaceflight vehicle or habitat which is used to conduct one or more segments of a multi-segment or multi-vehicle mission, even if their isolated segment would have allowed for higher exposures on its own.

Missions may be comprised of consecutive segments that occur in different vehicles, take place in different locations in space with varying distances from Earth, and last for different durations. Many requirements that pertain to cumulative exposures and conditions (such as Permissible Exposure Limits) have been tailored (relaxed) to accommodate short missions

occurring in single vehicles. However, for multi-segment or multi-vehicle missions, cumulative exposure over the entire duration of the mission needs to be considered. Exposure in one vehicle that is occupied for a segment of the full mission duration cannot be taken in isolation of the rest of the mission. It is not advisable for each vehicle to maintain its own short duration exposure requirements and expect other vehicles or habitats in the mission to lower their exposure limits to compensate for a higher exposure level in another vehicle. Similarly, a vehicle cannot expect other vehicles within the enterprise to compensate for lack of countermeasures in that vehicle.

1.3 Tailoring

In accordance with NPR 7120.5, NASA Space Flight Program and Project Management Technical requirements, tailoring is the process used to adjust or seek relief from a prescribed technical requirement to accommodate the needs of a specific task or activity (e.g., program or project). The tailoring process results in the generation of deviations and waivers depending on the timing of the request. The tailoring of the technical requirements from this NASA Technical Standard for application to a specific program or project **shall** be formally documented as part of program or project requirements and require formal approval from the HMTA/OCHMO by the NASA Chief Health and Medical Officer or delegated Program Representative in accordance with NPR 7120.5.

1.4 Authority

NASA policy for establishing Standards to provide health, performance, and medical programs for crewmembers during all phases of spaceflight and to protect the health, performance, and safety of the crew is authorized by NPD 1000.3, The NASA Organization, and NPD 8900.5, NASA Health and Medical Policy for Human Space Exploration.

2. APPLICABLE DOCUMENTS

2.1 General

2.1.1 The documents listed in this section contain provisions that constitute technical requirements of this NASA Technical Standard as cited in the text.

2.1.2 The latest issuances of cited documents apply unless specific versions are designated.

2.1.3 Use of a version other than as designated must be approved by the delegated Health and Medical Technical Authority

2.1.4 Applicable documents may be accessed at https://standards.nasa.gov or obtained directly from the Standards Developing Body or other document distributors. When not available from these sources, information for obtaining the document is provided or user should contact the office of primary responsibility or Center Library.

2.1.5 References are provided in Appendix A.

2.1.6 Acronyms, abbreviations, and symbols are provided in Appendix B.

2.1.7 Definitions are provided in Appendix C.

2.2 Government Documents

NASA

HEOMD-003	Crewed Deep Space System Human Rating Certification Requirements and Standards for NASA Missions
JSC - 26546	NASA International Space Station Flight Surgeon Training and Certification Plan
JSC - 67378	Nutritional Requirements for Exploration Missions up to 365 days
NASA/SP-2010-3407	Human Integration Design Handbook (HIDH)
NASA/SP-20210010952	NASA Human Systems Integration Handbook https://ntrs.nasa.gov/citations/20210010952
NASA/TP-2014-218556	Human Integration Design Process (HIDP)
NASA-STD-3001	NASA Spaceflight Human System Standard, Volume 2: Human Factors, Habitability, and Environmental Health
NPD 1000.3	The NASA Organization

NASA

NPD 8900.1	Medical Operations Responsibilities in Support of Human Space Flight Programs
NPD 8900.15	To Research, Evaluate, Assess, and Treat (TREAT) Astronauts Policy
NPD 8900.3	Astronaut Medical and Dental Observation Study and Care Program
NPD 8900.5	NASA Health and Medical Policy for Human Space Exploration
NPR 7120.11	NASA Health and Medical Technical Authority (HMTA) Implementation
NPR 7120.5	NASA Space Flight Program and Project Management Technical Requirements
NPR 7123.1	NASA Systems Engineering Process and Requirements
NPR 8705.2	Human Rating Requirements for Space Systems
OCHMO-STD-100.1A	NASA Astronaut Medical Standards Selection and Annual Recertification
SSP-51721	ISS Safety Requirements Document

2.3 Non-Government Documents

None

2.4 Order of Precedence

2.4.1 The technical requirements and standard practices established in this NASA Technical Standard do not supersede or waive existing technical requirements and standard practices found in other Agency documentation, or in applicable laws and regulations unless a specific exemption has been obtained by the NASA Chief Health and Medical Officer (CHMO).

2.4.2 Conflicts between this NASA Technical Standard and other technical requirements documents will be resolved by the NASA CHMO.

3. HEALTH AND MEDICAL CARE

Crewmember health care starts at selection, is implemented throughout training, spaceflight missi Artemis Food Risk - Loss of Food/Nutrition and Food Poisoning ons, and post-mission reconditioning, and continues past retirement from the astronaut corps via the TREAT (To Research, Evaluate, Assess, and Treat) Astronauts Act, which authorizes NASA to monitor, diagnose, and treat medical and psychological conditions associated with spaceflight for NASA (US government) astronauts. Deeply rooted in preventive medicine, aerospace medicine puts an emphasis on preventive care, while being prepared to respond to the known physiological and psychosocial challenges of spaceflight, as well as unexpected illness and injury that could afflict crewmembers due to their active lifestyles, their training for flight, their missions in space, and their post-mission recovery.

The following technical requirements reflect this comprehensive approach to crewmember health and well-being, addressing screening, preventive health strategies, medical care, contingencies during launch and landing, and post-mission healthcare, reconditioning and long-term monitoring. Refer to Figure 3.1-1—Health and Medical Care Technical Requirements Overview for an overview of the Health and Medical Care technical requirements.

Of note, the term "in-mission" which is introduced in this section of this NASA Technical Standard covers all phases of the mission, from launch, through landing on a planetary body and all surface activities entailed, up to landing back on Earth. Appendix D contains a requirements compliance matrix which provides additional information relative to health and medical care technical requirements described in this section.

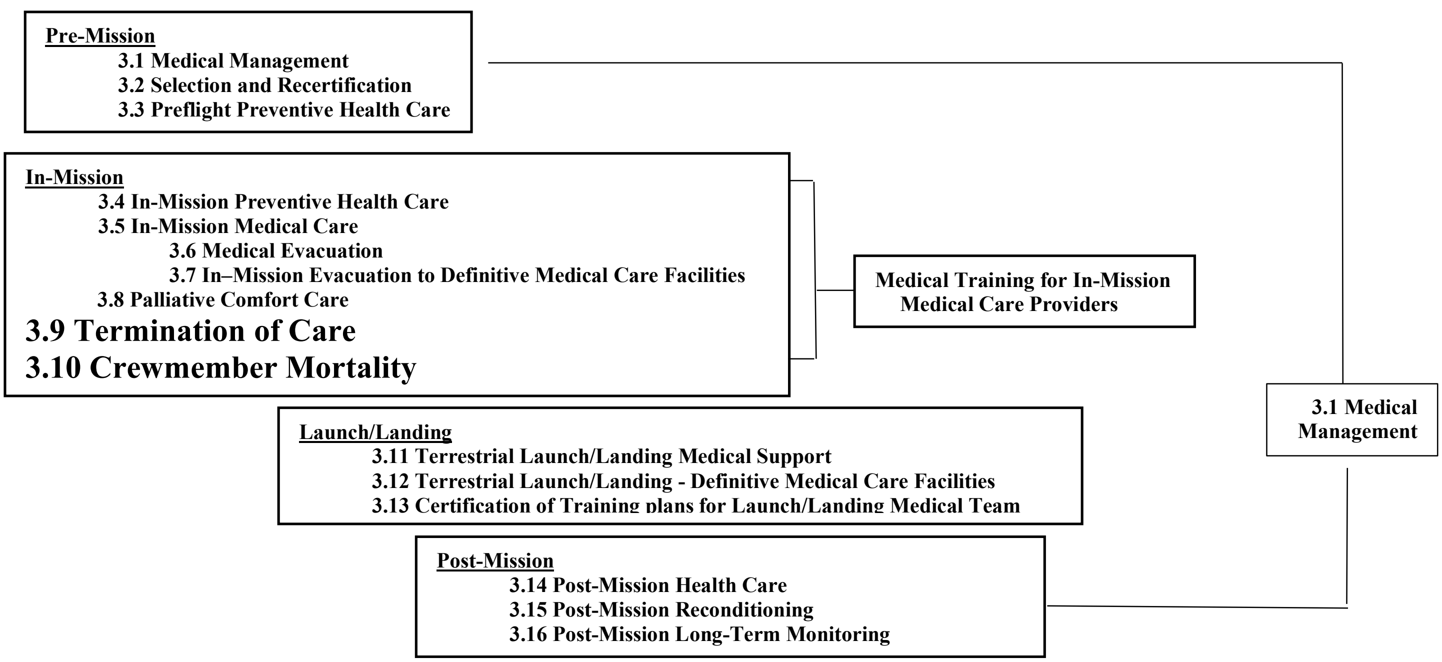

Figure 3.1-1—Health and Medical Care Technical Requirements Overview

3.1 Medical Management

[V1 3000] All terrestrial and in-mission medical aspects included in this NASA Technical Standard **shall** be in accordance with current U.S. and appropriate partners medical care standards, with limitations as imposed by mission constraints, and managed by the Flight Medicine team, which includes, but is not limited to: the Flight Medicine Clinic, Flight Surgeon, Deputy Flight Surgeon, and their designees, including the in-mission medical care providers (Crew Medical Officers).

3.2 Selection and Recertification

[V1 3001] Crewmembers **shall** be medically and psychologically selected and annually recertified following the guidance in OCHMO-STD-100.1A, NASA Astronaut Medical Standards Selection and Annual Recertification.

[Rationale: Medical and psychological screening is required for all crewmembers that fly on/to NASA vehicles or otherwise interact with NASA crewmembers. Medical screening reduces crewmember health risks in-mission and post-mission, along with increasing mission success. The scope of initial screening may be influenced by mission duration, distance from Earth, and criticality of individual crewmember functions (pilot, extravehicular activities (EVAs), robotic operations, spaceflight participant, etc.). Similarly, mission-specific screening, if required, will consider mission duration, distance from Earth, radiation exposure, mental/behavior analysis, and criticality of individual crewmember functions (pilot, EVAs, robotic operations, spaceflight participant, etc.).]

3.3 Pre-Mission Preventive Health Care

[V1 3002] Pre-mission preventive strategies **shall** be used to reduce in-mission and long-term health medical risks, including, but not limited to:

a. Optimization of nutrition.

b. Vitamin D supplementation.

c. Assessment of medications needed for in-flight use.

d. Triennial imaging of bone mineral density.

e. Maintenance of optimal aerobic and strength physical fitness.

f. Maintenance of flexibility, agility, and balance.

g. Annual and pre-flight physicals/periodic health evaluations.

h. Preventive dental care.

i. Vaccinations as recommended by CDC and local epidemiological conditions as recommended by flight medicine team (e.g., influenza, tetanus toxoid, varicella zoster vaccine, severe acute respiratory syndrome (SARS), coronavirus (COVID-19), etc.).

j. Behavioral health and performance training.

k. Flight surgeon monitoring of crewmembers during hazardous training and pre-flight science testing.

l. Total radiation dose control/monitoring.

m. Pre-mission Health-Stabilization Program (HSP) to reduce the likelihood of contracting an infectious disease before launch.

n. Assisted Reproductive Technology (ART) if desired by the crewmember to preserve gametocytes prior to missions with exposure to radiation.

[Rationale: Preventive health care tests, procedures, and interventions are required to ensure health pre-mission, during the mission, as well as for the post-mission lifetime of the crewmember. The longer the mission and the farther from Earth (and therefore from definitive care), the greater the extent of preventive interventions that will need to be implemented. Preventive care starts at selection and continues throughout the crewmember's career, including during missions.]

3.4 In-Mission Preventive Health Care

[V1 3003] All programs **shall** provide training, in-mission capabilities, and resources to monitor physiological and psychosocial well-being and enable delivery of in-mission preventive health care, based on epidemiological evidence-based probabilistic risk assessment (PRA), individual crewmember needs, clinical practice guidelines, flight surgeon expertise, historical review, mission parameters, and vehicle-derived limitations. These analyses consider the needs and limitations of each specific vehicle and design reference mission (DRM) with particular attention to parameters such as mission duration, expected return time to Earth, mission route and destination, expected radiation profile, concept of operations, and more. In-mission preventive care includes, but is not limited to:

a. Periodic monitoring of general health status.

b. Optimization and periodic monitoring of nutrition intake – To include caloric density and macro/micronutrients (including antioxidants, flavonoids, lycopene, omega-3 fatty acids, lutein, sterols, and prebiotics), to support multiple physiological systems such as immune function, bone and muscle health, effectiveness of radiation damage repair mechanisms, cognitive and mental well-being, microbiome, etc. Optimization of nutrition intake also includes aspects such as food palatability and food variety to support psychological well-being and crew morale.

c. Vitamin D supplementation – For bone and immune function.

d. Maintenance and periodic monitoring of aerobic and strength physical fitness – For maintenance of muscle strength and aerobic capacity (essential for performance of safety-critical physical tasks such as emergency vehicle egress), bone strength, cardiovascular health, immune system performance, sensorimotor function, behavioral health/stress relief, and reduction in renal stone formation.

e. Maintenance and periodic monitoring of flexibility, agility, and balance – For sensorimotor function (essential for performance of safety-critical physical tasks such as emergency vehicle egress).

f. Maintenance and monitoring of work/rest schedules and optimal sleep/circadian rhythm.

g. Maintenance and monitoring of environmental parameters at optimal levels for crew health and performance, as outlined in other technical requirements.

h. Prevention of pressure-related illness or injury (dysbarism) by utilizing the appropriate prebreathe and equipment protocols.

i. Preventive dental care.

j. Hearing conservation and protection (as required in [V2 9057] Hearing Protection Provision), including periodic monitoring.

k. Optimization and periodic monitoring of psychosocial countermeasures for team cohesion, privacy, social isolation, and sensory deprivation.

l. Preventive measures for orthostatic intolerance and neuro-vestibular challenges during G-transitions and adaptation to a new gravity environment.

m. Spaceflight Associated Neuro-Ocular Syndrome (SANS) periodic monitoring, and prevention with to-be-determined countermeasures (to be validated by research in the coming years).

n. Periodic monitoring of vascular motility and patency of venous drainage pathways in the neck as well as deep veins in the lower extremities.

o. Optimization and periodic monitoring of immune function via implementation of a suite of multi-component countermeasures.

p. For missions that land on planetary bodies – Training, capabilities, and resources for rehabilitation on the planetary surface, analogous to the functions of the post-Earth-landing recovery team, rehabilitation team, and flight surgeon team to enable surface mission success.

q. Monitoring and management of any future risks as they emerge.

[Rationale: In-mission preventive medical care, health care tests, procedures, and interventions are required to ensure and maintain health throughout the mission. The term "in-mission" covers all phases of the mission, from launch, through landing on a planetary body and all surface activities entailed, up to landing back on Earth. In-mission capabilities will vary by vehicle mass, volume, and power limitations and DRM considerations, thus in-mission preventive healthcare is to be tailored to specific mission needs and will subsequently affect risk assessment and pre-mission preventive care accordingly. For an overview of the PRA process and a representative (non-exhaustive) list of medical conditions considered of either high-likelihood or high-consequence for spaceflight missions, please see Appendix E, Table E.2-1—Sample IMM Output.]

3.5 In-Mission Medical Care

[V1 3004] All programs **shall** provide training, in-mission medical capabilities, and resources to diagnose and treat potential medical conditions based on epidemiological evidence-based PRA, individual crewmember needs, clinical practice guidelines, flight surgeon expertise, historical review, mission parameters, and vehicle-derived limitations. These analyses consider the needs and limitations of each specific vehicle and design reference mission (DRM) with particular attention to parameters such as mission duration, expected return time to Earth, mission route and destination, expected radiation profile, concept of operations, and more. In-mission capabilities (including hardware and software), resources (including consumables), and training to enable in-mission medical care, and behavioral care, are to include, but are not limited to:

a. Medical system architecture and infrastructure (i.e., electronic medical records (including data encryption/protection), inventory monitoring/maintenance, medical stowage allocation (including pressurized or refrigerated volume), etc.).

b. Medical kits (personal, routine, emergency, and survival) and resources, including appropriate pharmaceuticals, equipment, and supplies selected for ease-of-use, and personal protective equipment (e.g., biohazards and sharps containment).

c. Configuring environment for medical care (including privacy considerations).

d. Obtaining and recording history of medical encounters.

e. Performing and recording the physical exam.

f. Periodic monitoring and treatment of dental health as appropriate.

g. Capability to provide deployed crewmembers with optical correction (e.g., glasses) with increased levels of power to mitigate SANS-induced changes in refractive error.

h. Assessing, recording, monitoring, and trending vital signs and additional physiological and behavioral health signs.

i. Conducting ancillary tests as needed, including imaging (e.g., cardiac, vascular, ocular), laboratory analyses, and electrocardiography.

j. Performing procedures and recording outcomes.

k. Providing physical restraints for the patient, caregiver, and medical equipment appropriate to specific gravity environments of the mission con-ops.

l. Recording treatment plans and its execution as appropriate.

m. Administering and managing all medications.

n. Consumables.

o. Capability to diagnose and treat pressure related illness or injury (dysbarism).

p. Monitoring and balancing work/rest schedule.

q. Treating neurobehavioral disorders with medical devices and/or evidence-based asynchronous behavioral health treatment protocols available on electronic devices.

r. Private two-way communication (e.g., audio, video, messaging, images) with ground medical and psychological support, family, and crew support system.

s. Private transmission of medical data (including imaging) to ground medical support or other mission vehicles.

t. Means of providing autonomous medical care and advanced life support.

u. Medical evacuation.

v. Palliative care.

[Rationale: Aspects to be considered in the PRA include, but are not limited to: Mission duration, destination, return-to-Earth capability, mission architecture, spacecraft design, launch/landing loads, crew selection standards, the program's Health Stabilization Program (HSP), and the need for autonomous-from-Earth medical capabilities. In-mission medical care will be in accordance with current U.S. medical care practices with limitations as imposed by mission constraints and managed by the Flight Surgeon, Deputy Flight Surgeon, or their designees. The term "in-mission" covers all phases of the mission, from launch, through landing on a planetary body and all surface activities entailed, up to landing back on Earth. As each mission may be comprised of consecutive phases that occur in different vehicles, take place in different locations in space with varying distances from Earth, and last for different durations, coordination of onboard medical resources occurs between the medical providers of the different vehicles to ascertain comprehensive care capabilities that allow a successful mission from start to finish.

Medication and supplies are designed to treat the most likely and most impactful medical issues encountered on each DRM/vehicle while abiding by factors including but not limited to storage, vehicle or suited environment, weight/volume, and expiration date. Medications are stored to be *accessible and used in a timely fashion. Considerations for medications to be used while a crewmember is suited will need to be assessed for use related to [V2 11027] Suited Medication Administration. All standard medical and survival kits are evaluated per Safety requirements including pharmaceuticals off-gassing toxicity (for example SSP-51721 ISS Safety Requirements Document). Crew specific medical kits are packaged for each individual crewmember based on their medical needs.*

For an overview of the PRA process and a representative (non-exhaustive) list of medical conditions considered of either high-likelihood or high-consequence for spaceflight missions, please see Appendix E, Table E.2-1—Sample IMM Output.]

Deleted.

Requirement [V1 3005] deleted.

Moved.

Requirement [V1 3006] moved to section 5.2.

3.6 Medical Evacuation

[V1 3007] Medical evacuation to a location with a higher level of medical care **shall** be available for illness/injuries occurring during a spaceflight mission which are beyond the medical capabilities available at the crew's location.

[Rationale: This might entail evacuation to planetary or orbiting assets, or back to Earth, depending on the scenario, medical needs, and availability of resources at each location. The limitations of onboard medical capabilities (including trained medical professionals) means that some illnesses or injuries may require medical interventions beyond those which can be provided during the mission. Assuming a guiding philosophy that preservation of life supersedes preservation of the mission, such severe medical occurrences will necessitate aborting the mission and returning the ill or injured crewmember to Earth for definitive medical care. Depending on mission parameters and orbital dynamics, a return to Earth may not be possible, or may take such a long time as to be rendered futile. In other cases, higher medical capability may be available on a closer-than-Earth asset, either in orbit or on a planetary surface and may be used as a temporizing measure before returning to Earth, or as the location of definitive care.]

3.7 In-Mission Evacuation to Definitive Medical Care Facilities

[V1 3008] Plans and vehicle(s) **shall** be available to transport severely ill or injured crewmember(s) to appropriate Medical Care Facilities, including Definitive Medical Care Facilities (DMCF) in the event of a contingency scenario.

[Rationale: If a return to Earth of a severely ill or injured crewmember is possible and is undertaken, coordination with suitable DMCFs in proximity to potential landing sites will be made in advance of the crewmember's landing to ascertain readiness of the facility to accept and

implement immediate medical care. Mobile ground resources with the capability to initiate medical care enroute to the DMCF will be deployed at potential landing sites.]

3.8 Palliative Comfort Care

[V1 3009] The program **shall** provide in-mission palliative comfort care capabilities for medical scenarios where onboard medical resources have been exhausted, or a timely return to Earth (or another location of higher medical capability) is not feasible, and survival of the crewmember has been determined to be impossible.

[Rationale: Certain medical conditions may occur during a spaceflight mission for which treatment was not manifested, either because those conditions were considered unlikely to occur or were considered to require care beyond that which is feasible for such a mission. If a crewmember were to experience such an illness or traumatic injury for which therapeutic care is not available, palliative care is provided to relieve pain, anxiety, and other types of discomfort. The main medical conditions which have the potential to require palliative care include, but are not limited to, severe trauma, abdominal injury, severe burns, head injury, neck injury, cardiogenic shock, hypovolemic shock, neurogenic shock, radiation sickness, and sepsis. Palliative comfort care may include administration of long-acting analgesics, antiemetics, supplemental oxygen, sedation, other symptom management, and psychosocial support (including religious and cultural if requested) from the ground for the ill or injured crewmember as well as for the rest of the crew.]

3.9 Termination of Care

[V1 3010] Each human spaceflight program **shall** have criteria for termination of care available prior to flight.

[Rationale: Several medical scenarios could conceivably end with a decision to terminate medical care. Catastrophic injury or very severe illness could be such that either the resources required to sustain life or definitively treat are not available or have been depleted, and/or the medical training of the medical care provider could be insufficient to support such critical and complex medical care. In these rare scenarios, medical care that had begun may need to be withdrawn and palliative comfort care provided, either because of the extreme futility of the situation, because all relevant medical resources have been used and are no longer available, or because continuation of futile measures will completely deplete medical resources and could compromise the survival of the remaining crew if the mission cannot be aborted and medical resources will be needed later on in the mission. The ethical and moral implications of a decision to terminate care are complex and will impact both the surviving crew and the assigned flight surgeons. Policy, procedures, and training prior to flight may be helpful in preparing for such scenarios.]

3.10 Crewmember Mortality

Deleted.

Requirement [V1 3011] updated into [V1 3050], [V1 3051], [V1 3052], [V1 3053], [V1 3054], [V1 3055], [V1 3056].

Despite screening, health care measures, onboard medical interventions, and safety precautions including engineering controls, it is possible for crewmembers to die during a mission, particularly on extended duration missions. Problems that can threaten the health and safety of remaining crewmembers include trauma, grief, mission delays, and contamination. Facilities and plans for handling deceased crewmembers that are socially, psychologically, biologically, culturally, and physically acceptable are to be established during system development. The plan needs to consider the following factors: minimizing risk to surviving crewmembers, potential forensics collection, biohazard containment (via pressurized suit or human remains containment unit), remains return or in-situ disposition, investigation plan, psychological support plan, and legal jurisdiction which will involve working with other federal agencies (such as the Federal Bureau of Investigation) and international partners (via treaties).

3.10.1 Pre-Mission Crew Mortality Plan

[V1 3050] The program **shall** develop and execute a Crew Mortality Plan and determine legal jurisdiction prior to each mission (including pre-flight activities, launch, operations, and landing).

[Rationale: The plan will need to consider individual crewmember desires, including cultural and religious preferences (e.g., is autopsy permissible, what death rituals are to be performed) respectful handling and containment of remains, federal (e.g., Federal Bureau Investigation, Federal Aviation Administration, Space Force, Armed Forces Medical Examiner, National Transportation and Safety Board, Department of Defense, etc.) and international agencies' requirements (if applicable). This is to ensure proper handling of the remains and the reporting of events is executed in alignment with cultural practices and legal technical requirements. The plan will need to consider all procedures involved during the postmortem process. For in situ burial or jettison of a body into space, shrouding remains will also need to be considered where possible to prevent additional distress to surviving crew/kin by remote imagery collection or distribution. A criminal investigation will take place if deemed necessary by the circumstances of the death.]

3.10.2 Pronouncement of Crew Death

[V1 3051] The program **shall** define the process to medically assess the death of an in-mission crewmember and legally record the pronouncement of death.

[Rationale: Assessment of death requires the medical capability to assess the crewmember and legally record the death per any state, federal, or international regulations. In some instances, causes of death will be approximated, as the cause and manner of death may be determined without an autopsy examination. Jurisdiction and the process for implementation are to be established in the Crew Mortality Plan prior to the mission and factor in remote mission operations that may impede or prevent direct medical assessment of the deceased crewmember.]

3.10.3 In-Mission Forensic Sample Collection

[V1 3052] The program **shall** have the capability to obtain in-mission forensic evidence from a deceased crewmember and return this evidence to Earth.

[Rationale: Forensic samples and evidence are desired to understand the circumstances surrounding a fatal event. The forensic evidence (which may include biological sampling, environmental data and/or sampling, operational parameters, etc.) and medicolegal authority for collection and storage of such evidence will be determined in the Crew Mortality Plan prior to each mission. This will include pre-mission coordination with crewmembers and families, federal agencies, and international partners. Implementation of forensic sampling or data collection by surviving crew in-mission will have a clear purpose associated with the event investigation and necessary detail of cause, and not put surviving crew at increased risk of physical or psychological harm. Prior to initiating forensic sampling, continuous assessment of the psychological suitability and willingness of the surviving crewmembers to participate would be conducted such that sampling procedures are terminated at any time that a surviving crewmember is deemed unfit or unwilling to continue. Vehicle design and capability considerations related to the disposition of the crewmember remains will need to meet the requirement as referenced in [V2 6061] Environment Cross-Contamination.]

3.10.4 Crew Mortality Remains Return to Earth

[V1 3053] The program **shall** be capable of returning the remains of a deceased crewmember back to Earth.

[Rationale: Return of the remains of a deceased crewmember is of high priority, however, return of the remains of a crewmember who dies in-mission are not to jeopardize the safe return and psychological wellbeing of surviving crewmembers. Containment of remains considers the length of time a body can be kept in a suit or human remains pouch for each mission. Return will require the ability to control the remains in a sealed or temperature-controlled environment for the period of time necessary to return to Earth. Ability to transport the remains into a vehicle without injury to surviving crew, as well as within the vehicle during return to Earth are to also be considered. Vehicle design and capability considerations related to the disposition of the crewmember remains will need to meet the requirement as referenced in [V2 6061] Environment Cross-Contamination and consider natural processes such as rigor mortis that may set in within hours and last a few days, which may delay or prevent containment, transport, or restraint of remains. Also, reference [V1 3055] Surviving Crew Support for considerations on behavioral health when returning remains.]

3.10.5 In Situ Disposition of Deceased Crewmember Remains

[V1 3054] The program **shall** meet planetary protection regulations in the case of in situ or jettison disposition of the remains of a deceased crewmember.

[Rationale: Returning the remains of a crewmember who dies in-mission may not be desired due to cultural reasons or be feasible due to risk to other crewmembers (potential toxicological exposures, disease exposure, psychological harm, etc.) or mission circumstances (inability of vehicle or transit duration to accommodate return, inability to extract crewmembers from surface location, etc.). Leaving the remains in situ are to consider planetary protection regulations as well as cultural and technical requirements. This information can be found in the Committee for Space Research

(COSPAR) Policy for Planetary Protection, an accepted approach for complying with the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (UN, 1967), Article IX. Additionally, planetary protection categories and guidance to determine the applicability and extent of planetary protection measures for extraterrestrial environments as well as for return to Earth are documented in NPD 8020.7, Biological Contamination Control for Outbound and Inbound Planetary Spacecraft, and NID 8715.129 (or superseding documents) for the Moon and Mars. Vehicle design and capability considerations related to the disposition of the crewmember remains will need to meet the requirement as referenced in [V2 6061] Environment Cross-Contamination.]

3.10.6 Surviving Crew Support

[V1 3055] The program **shall** provide behavioral health support to the deceased crewmember's family, surviving crewmembers, and support team in-mission and post-mission.

[Rationale: The program will develop an integrated (including all agencies involved) behavioral health contingency response protocol that identifies and manages adverse behavioral health impacts in affected members in order to meet cultural and organizational needs. Common elements of the contingency response will include, but are not limited to:

a. Coordinating extra Private Psychological Conferences (PPCs), either individually or as a group. PPCs will provide surviving crewmembers psychoeducation on grief and trauma reactions, conduct an assessment of psychological functioning, and identify needs for support (i.e., communication with support system, scheduling follow-up PPCs, management of crew time/tasks.

b. Coordinating Private Family Conferences (PFCs) for surviving crewmembers.

c. Providing counseling/support to crewmember families.

d. Consultation and collaboration with the NASA and International Partner (IP) Psychologists and Psychiatrists on how to best support crewmembers and their families.

e. Delivery of grief process briefs to impacted groups (e.g., crewmembers, crewmember families, flight surgeons, ground operations personnel).

f. Post-mission debriefs to monitor for delayed onset of mental health issues.

Loss of a crewmember in-mission will significantly impact the surviving members and support team (i.e., ground support), both in-mission and post-mission. Surviving crewmembers' excessive exposure and manipulation of the deceased crewmember's body during the forensic sampling process increases the risk of acute or delayed mental health injury. This risk is compounded with non-medical crew performing invasive procedures on a close friend or colleague. Assessment of behavioral health in-mission may also drive decision making associated with forensic sample collection and whether to return remains to Earth.]

3.10.7 Crew Mortality Mishap Investigation Plan

[V1 3056] The program **shall** have plans in place prior to a mission to gather the appropriate data to support a Presidential Commission mishap investigation.

[Rationale: The NASA Authorization Act of 2005 (Public Law 109-155, Section 821) mandates that any vehicular disaster involving significant injury or loss of life to onboard NASA crewmembers establishes a Presidential Commission, with federal oversight of mishap response and investigation. Refer to NPR 8621.1, NASA Procedural Technical requirements for Mishap and Close Call Reporting, Investigating, and Recordkeeping for further guidance.]

3.11 Terrestrial Launch/Landing Medical Support

[V1 3012] All programs **shall** have medical capability at the site of terrestrial launch and landing to address nominal operations and launch/landing contingencies, including, but not limited to the following:

a. HSP technical requirements for the crew, the crew's family, and supporting personnel for purpose of disease prevention.

b. Access to the full spectrum of medical capabilities, from routine medical and behavioral health care to advanced trauma life support (ATLS) capabilities, advanced cardiac life support (ACLS), or equivalent.

c. Incorporation of civilian and/or Department of Defense (DOD) facilities and Emergency Medical Services (EMS).

[Rationale: Medical support for terrestrial launch and landing needs to consider the local geographic conditions. Technical requirements are provided in the Program Medical Operations Requirements Document (MORD) or similar document and in a Program Technical Requirements Document (PRD) or similar document to task outside agencies for EMS support and ensure its implementation. Medical support at all primary landing sites is to be sufficiently uniform, without disparity between standards of care. If there is no Definitive Medical Care Facility that satisfies the technical requirement for high-quality emergency treatment, mobile or fixed medical suites onsite are to be provided or engaged to protect crew health and afford the capability of resuscitation.]

3.12 Terrestrial Launch/Landing - Definitive Medical Care Facility (DMCF)

3.12.1 DMCF Medical Care

[V1 3013] The program **shall** establish medical care agreements with DMCF(s) for each launch and landing (nominal and contingency) location.

[Rationale: It is critical to have pre-established medical care agreements with at least one DMCF for each launch and landing location to ensure timely access to appropriate medical care for crew and ground support personnel.]

3.12.2 DMCF Transport

[V1 3014] The program **shall** have the capability to transport crewmembers to a DMCF for each launch and landing (nominal and contingency) location.

[Rationale: Depending on the location of the launch/landing contingency, transport capabilities may involve evacuation via ground, water, or air by prepositioned civilian and/or DOD assets. All rescue vehicles are to have ATLS or equivalent capabilities to sustain the crewmember until transfer to a DMCF.]

3.13 Certification of Training Plans for Launch/Landing Medical Team

[V1 3015] The organization responsible for crewmember health **shall** certify training plans for internal NASA medical support personnel who work launch/landing and concur on training plans for external organizations that have a specific medical support training plan in support of a NASA spaceflight program. Training includes, but is not limited to:

a. Physiological changes occurring as a result of prolonged launch body posture.

b. Spaceflight physiology.

c. Injuries resulting from launch and landing contingencies (such as trauma, burns, hypoxia, and hypothermia).

d. Hazards of exposure to space vehicle-associated toxic chemicals such as propellant, fuels, oxidizers, thermal control fluids, off-gassed products, and their unique treatments and responses.

e. Launch/landing suit, helmet, and equipment configuration and safe removal.

f. Vehicle-specific failure modes and resulting injury profiles.

g. Environmental considerations specific to nominal and off-nominal recovery conditions.

[Rationale: General medical support training including specific training to prepare the medical support providers to work at a launch/landing site and provide care to crewmembers.]

3.14 Post-Mission Health Care

[V1 3016] Post-mission health care **shall** be provided to minimize occurrence of deconditioning-related illness or injury, including but not limited to:

a. Physical examinations by a flight surgeon or designated medical support personnel immediately following landing and periodically thereafter, until crewmember status is stable.

b. Clinical laboratory tests including but not limited to imaging.

c. Physical reconditioning (see [V1 3017] Post-Mission Reconditioning).

d. Treatment as required.

e. Scheduled days off and rest periods.

f. Circadian rhythm entrainment.

g. Nutrition assessment and support.

h. Behavioral health support for the crewmember and their families to assist with transition back into work and family life.

i. Monitoring by a flight surgeon during post-mission scientific investigations that may pose some risk to a deconditioned crewmember's health.

[Rationale: Post-Mission health care tests, procedures, and interventions are required to reduce risk of deconditioning injury or illness to ensure the post-mission health of the crewmember. This may include but is not limited to physical deconditioning, immunosuppression/risk of infection, and physiological and psychological needs of the crewmember during transition back to terrestrial life.]

3.15 Post-Mission Reconditioning

[V1 3017] All programs **shall** provide the planning, coordination, and resources for an individualized post-mission reconditioning program, specific to each crewmember, mission type, and mission duration. The post-mission reconditioning starts with crew egress at landing and includes a guided, phased reconditioning protocol. The goals of the reconditioning program include the following:

a. To ensure the health and safety of returning crew.

b. To actively assist the crew's return to full functional abilities and return-to-flight status.

c. To actively assist in the crew's return to pre-mission fitness

[Rationale: Post-Mission reconditioning is provided to reduce the risk of deconditioning, injury, or illness and to ensure the post-mission health of the crewmember.]

3.16 Post-Mission Long-Term Monitoring

[V1 3018] Crewmembers returning from spaceflight **shall** be monitored longitudinally for health, behavioral health, and well-being parameters in a standardized manner.

[Rationale: Data derived from standardized testing procedures, used in a pooled, non-attributable fashion, are essential to characterize the short and (in particular) the long-term effects of spaceflight on human health (occupational surveillance). Exposure metadata from flight monitoring is a critical component correlating exposure to health outcomes and it is important to make such data accessible.]

4. HUMAN PERFORMANCE

To support space exploration and to guide and focus efforts to protect the health of spacefaring crews, spaceflight health technical requirements for human performance have been developed. These technical requirements provide a declaration of acceptable medical risk from the deleterious health and performance effects of spaceflight and help target and prioritize biomedical research and technology development efforts, providing target parameters for products and deliverables that support the health maintenance of crews during space missions. They also promote operational and vehicle design technical requirements and aid in medical decision-making during space missions.

The technical requirements are based on the best available scientific and clinical evidence. Research findings, lessons learned from previous space missions and in analogue environments, current standards of medical practice, risk management data, and expert recommendations were all considered in the process of setting the technical requirements. The process used for setting the technical requirements was modeled on that used by the United States Occupational Safety and Health Administration (OSHA) but were tailored to meet the unique needs and characteristics associated with the human health aspects of space exploration and the NASA mission.

4.1 Fitness-for-Duty Aerobic Capacity

An individual's aerobic capacity influences the ability to perform a task at a given level of work. Aerobic capacity in conjunction with the operational concept provides an upper bound for oxygen (O_2) demand. Aerobic capacity is determined by calculating VO_{2max} which measures the maximum rate of oxygen a body can use during exercise/activity. Setting aerobic fitness for duty parameters is necessary to ensure the crew can perform required functions during all phases of spaceflight including extravehicular activities. Crew is provided with countermeasures enabling them to maintain their aerobic capacity throughout a mission including post-mission reconditioning.

4.1.1 Microgravity EVA Aerobic Capacity

[V1 4001] Crewmembers **shall** maintain an in-mission VO_{2max} at or above 32.9 ml/min/kg for missions with microgravity EVAs as determined by either direct or indirect measures.

[Rationale: Expected EVA metabolic rates were determined based either on flight data or analog study data. The estimated microgravity data came from an unpublished database of Shuttle and ISS EVA metabolic rates and Neutral Buoyancy Laboratory (NBL) training metabolic rates. Data used for the ISS scenario were the flight metabolic data from Space Transportation System (STS)-114 through STS-135. These data were reported in kcal/hr and transferred into VO_2 ml/min/kg using an assumed respiratory exchange ratio (RER) of 0.85 and a crewmember mass of 80 kg. The average duration of these EVAs was 6.67 hours with a maximum of 8 hours. Based on these numbers, the assumption that crewmembers would sustain 30% of their in-mission VO_{2max} during EVA task performance was used to calculate the required in-mission VO_{2max} minimum. Pre-mission recommendations are provided given the historical experience showing declines of 15-25% in VO_{2max} but are not required as long as the in-mission VO_{2max} of 32.9 ml/min/kg can be maintained. (See Table 4.1-1—Pre-mission VO_{2max} Recommendations and Required Minimum In-mission VO_{2max}.) This recommended in-mission VO_{2max} would also be sufficient to address the

average max EVA VO_2, which was 19.4 ml/min/kg, and even the average of the top 10 EVA max VO_2 values, which was 32.3 ml/min/kg.]

Table 4.1-1— Pre-mission VO_{2max} Recommendations and Required Minimum In-mission VO_{2max}

Example Destination	In-Mission VO_{2max}	Pre-Mission VO_{2max} Recommendation (assuming an in-mission 15% decline)	Pre-mission VO_{2max} Recommendation (assuming an in-mission 25% decline)
ISS	32.9 ml/min/kg	38.7 ml/min/kg	43.8 ml/min/kg

4.1.2 Extraterrestrial Surface EVA Aerobic Capacity

[V1 4002] Crewmembers **shall** maintain an in-mission VO_{2max} at or above 36.5 ml/min/kg for missions with extraterrestrial surface EVAs as determined by either direct or indirect measures.

[Rationale: Extraterrestrial Surface EVAs are determined to require additional aerobic capacity compared to microgravity EVAs. Currently there is no data to inform extraterrestrial aerobic capacity, therefore historical experience (Apollo and ISS) as well as analog and terrestrial studies are being used with the aim of developing aerobic fitness standards for exploration missions. For example, the Functional Mission Task Study (Sutterfield et al. 2019) contributed to the estimated extraterrestrial surface EVA aerobic limit by providing terrestrial data used to predict extraterrestrial EVA performance. Crewmembers completed simulated mission critical tasks (surface traverse and hill climb) following max VO_2 cycling and rowing tests with conditions simulating ambulation during Lunar, Apollo missions, and ambulation in Mark III Space Suit Technology Demonstrator EVA Suit. Metabolic rates and max VO_2 were measured and evaluated for ability to predict task performance. Use of logistic regression and Receiver Operating Characteristic (ROC) analyses revealed that as metabolic demands of tasks increased, fitness threshold increased. For example, the most restrictive conditions included having crewmembers complete simulated traverse in weighted spacesuits which elicited an approximate 3.5 ml/min/kg increase in VO_2. This and similar data were considered as well as the terrestrial limit of 32.9 ml/min/kg (assuming ISS EVA working at 30-40% max aerobic capacity) to result in the current requirement of 36.5 ml/min/kg. Further studies are taking place and will continue to inform these prediction numbers.]

4.1.3 In-Mission Aerobic Capacity

[V1 4003] The in-mission aerobic capacity **shall** be maintained, either through countermeasures or work performance, at or above 80% of the pre-mission capacity determined by either direct or indirect measures.

[Rationale: A relative permissible loss of aerobic capacity requirement was established as part of the maintenance of overall cardiovascular health. A decreased VO_{2max} is a hallmark result of spaceflight and bedrest when conducted without application of effective countermeasures. Convertino et al. (1997) demonstrated a 6-16% reduction in VO_{2max} after 10 days of bedrest and additional expected reductions during longer duration. The Cromwell et al. 2019 70-day bedrest

study used mission-like ISS exercise equipment capability during long-duration bed rest as a spaceflight exercise analog and demonstrated improvements in VO_{2max} and muscle power. The in-mission ≥ 80% requirement was determined using historical (including ISS) and study data, see Scott. et al. (2023) Effects of exercise countermeasures on multisystem function in long duration spaceflight astronauts, that assumes average 15% decline in VO_{2max} and showed decrements up to 20% do not impair mission objectives and can be reconditioned to pre-flight aerobic capacity during post-flight reconditioning. This is in addition to the performance-based aerobic capacity technical requirements [V1 4001] Microgravity EVA Aerobic Capacity and [V1 4002] Extraterrestrial Surface EVA Aerobic Capacity. Both the relative and performance-based requirements are to be considered when aerobic exercise countermeasure capabilities are included in space systems.]

4.1.4 Post-Mission Aerobic Capacity

[V1 4004] Post-mission reconditioning **shall** be aimed at achieving a VO_{2max} at or above the crewmember's pre-mission values.

[Rationale: Aerobic capacity can be decreased by approximately 10%–30% after spaceflight depending on duration and conditions (NASA Human Research Program [HRP] Evidence report HRP-047072). Crewmembers follow documented Crewmember medical requirements (per [V1 6009] Medical and Crew Health Technical Requirements Document), max VO_2 is evaluated within 5-7 days of landing, and crewmembers are provided with a daily schedule of prescribed aerobic reconditioning exercises to enable them to return to pre-mission aerobic fitness. They are tested at pre-determined intervals to confirm reconditioning success.]

4.2 Fitness-for-Duty Sensorimotor

Sensorimotor functional capabilities include balance, locomotion, eye-hand coordination, gaze control, tactile perception, and spatial orientation. Crewmembers experience impacts to sensorimotor function during and following transitions in gravitational fields, such as during the launch and re-entry phases of spaceflight. These impacts can include vestibular dysfunction, motion sickness, spatial disorientation, and decrements in postural, locomotor, manual, and fine motor controls which can potentially result in impaired crew performance during launch, post-launch, landing and post-landing activities (e.g., capsule egress and EVAs). Sensorimotor function will be assessed throughout all aspects of the mission using metrics that are task specific. Countermeasures including pre- and in-flight training, post-landing assessments and reconditioning exercises, vehicle/system design, operational timelines, and pharmaceuticals will be provided to maintain sensorimotor function through all phases of flight including post-mission reconditioning. Requirements are written based on mission related activities and critical operations. For detailed discussions regarding the effects of spaceflight on sensorimotor/vestibular alterations, see chapter 5, Human Performance Capabilities, of the HIDH.

4.2.1 Pre-Mission Sensorimotor

[V1 4005] Pre-mission sensorimotor functioning **shall** be within normal clinical values for age and sex of the crewmember population.

4.2.2 In-Mission Fitness-for-Duty Sensorimotor

[V1 4006] In-mission Fitness-for-Duty technical requirements **shall** be guided by the nature of mission-associated critical operations (such as, but not limited to, vehicle control, robotic operations, and EVAs).

4.2.3 In-Mission Fitness-for-Duty Sensorimotor Metrics

[V1 4007] In-mission Fitness-for-Duty technical requirements **shall** be assessed using metrics that are task specific.

4.2.4 Sensorimotor Performance Limits

[V1 4008] Sensorimotor performance limits for each metric **shall** be operationally defined.

4.2.5 Sensorimotor Countermeasures

[V1 4009] Countermeasures **shall** maintain sensorimotor function within performance limits.

4.2.6 Post-Mission Sensorimotor Reconditioning

[V1 4010] Post-mission reconditioning **shall** be monitored and aimed at returning to baseline sensorimotor function.

4.3 Fitness-for-Duty Behavioral Health and Cognition

Cognitive capabilities include, but are not limited to, attention, memory, decision making, problem solving, logical reasoning, and spatial cognition that can impact both individual and/or team performance. Cognitive Workload is the user's perceived level of time-stress, mental effort, and frustration required to complete a task. It is influenced by many factors, including task load, task scheduling, and task design. Perceived high or low workload can lead to crew hurrying, compromised performance, and increased crew stress, perceived low workload can lead to crew boredom, low attention, and high error rates. Workload Assessment tools such as the Bedford Scale or NASA Task Load Index are used to determine workload demands that result in optimal crew health and performance. Crew schedule will have established limits to ensure crew physical and psychosocial health and safety. It is important to recognize the significant role that physical activity/exercise plays in maintaining crew health and well-being. Crewmember behavioral, psychosocial, and cognitive state will be assessed and monitored through all mission phases to ensure they remain within clinically accepted values.

4.3.1 Mission Cognitive Status

[V1 4011] Pre-mission, in-mission, and post-mission crew behavioral health and crewmember cognitive status **shall** be within clinically accepted values as determined by behavioral health evaluations.

4.3.2 End-of-Mission Cognitive Assessment and Treatment

[V1 4012] End-of-mission assessment and treatment for crewmember cognitive status **shall** include cognitive assessment, monitoring, and as needed, transitioning the crewmember back to pre-mission values.

4.3.3 End-of-Mission Psychosocial Assessment

[V1 4013] End-of-mission assessment and treatment for behavioral health of the crewmember **shall** include behavioral health and psychosocial assessment, monitoring, and as needed, transitioning the crewmember back into terrestrial work, family, and society.

4.3.4 In-Mission Completion of Critical Tasks

[V1 4014] The planned number of hours for in-mission completion of critical tasks and events, workday, physical activity/exercise, and planned sleep period **shall** have established limits to assure continued crew health and safety.

4.4 Fitness-for-Duty Hematology and Immunology

The immunological status of crewmembers may be compromised by physiological effects associated with elevated levels of stress due to long-term habitation in a microgravity environment. Monitoring hematological and immunological function and providing countermeasures to help sustain hematologic and immunologic health is important to ensure crew health.

4.4.1 Pre-Mission Hematological/Immunological Function

[V1 4015] Crewmember pre-launch hematological/immunological function **shall** be within normative ranges established for the healthy general population.

4.4.2 In-Mission Hematological/Immunological Countermeasures

[V1 4016] In-mission countermeasures **shall** be in place to sustain hematological/immunological parameters within the normal range as determined by direct or indirect means.

4.4.3 Hematology and Immunology Countermeasures and Monitoring

[V1 4017] Countermeasures and monitoring **shall** ensure immune and hematology values remain outside the critical values, i.e., the level that represents a significant failure of the hematological/immunological system, and is associated with specific clinical morbidity, defined for specific parameters.

4.4.4 Post-Mission Hematological/Immunological

[V1 4018] Post-mission assessment and treatment **shall** be aimed at returning to pre-mission hematological/immunological baseline values.

4.5 Permissible Outcome Limit for Nutrition

Maintaining crewmember nutritional status is critical to support crew health and optimal crew performance during missions. Crewmember nutritional status is assessed and monitored over all mission phases. Crewmember nutritional needs are calculated based on individual age, sex, body mass, height, and activity factor, to determine crewmember intake. Countermeasures are provided including prescribed diet and supplements, if necessary, to ensure that crewmembers have adequate nutritional intake and nutrients.

4.5.1 Pre-Mission Nutritional Status

[V1 4019] Pre-mission nutritional status **shall** be assessed, and any deficiencies mitigated prior to launch.

4.5.2 In-Mission Nutrient Intake

[V1 4020] Programs **shall** provide each crewmember with 100% of their calculated nutrient and energy requirements, based on an individual's age, sex, body mass (kg), height (m), and appropriate activity factor.

Deleted.

Requirement [V1 4021] deleted.

4.5.3 Post-Mission Nutritional Assessment and Treatment

[V1 4022] Post-mission nutritional assessment and treatment **shall** be aimed at returning to pre-mission baseline.

4.6 Permissible Outcome Limit for Muscle Strength

Skeletal muscle is essential to human health and functional performance as both a contractile tissue responsible for force production and a highly metabolic tissue influencing energy balance. Microgravity environments encountered in space travel can result in a loss of muscle mass and muscle strength. Maintaining adequate strength levels is essential for effective performance of spaceflight tasks, emergency egress from a vehicle, and general function upon return to Earth. Deconditioned crewmembers may be at increased risk for falls and difficulty with assigned tasks and activities of daily living upon return. Pre-mission muscle strength and function requirements are designed to provide sufficient strength to complete in-flight and post-flight tasks, while maintaining operational efficiency and preserving muscle strength for off-nominal events.

Countermeasures such as exercise devices are provided through all phases of a mission to maintain skeletal muscle strength.

4.6.1 Pre-Mission Muscle Strength and Function

[V1 4023] Pre-mission muscle strength and function **shall** meet or exceed the values in Table 4.6-1—Pre-Mission Muscle Strength.

[Rationale: Crewmember strength capacity is to be sufficient to complete in-flight and post-flight nominal tasks, maintain operational efficiency, minimize loss of mission objectives, and unaided egress. Table 4.6-1—Pre-Mission Muscle Strength Requirements, provides strength standards for missions with microgravity EVAs, extraterrestrial surface EVAs, and unaided egress. It may be possible for crewmembers who fall below these standards to complete tasks, however it could require additional time and resources. EVA suit design (i.e., suit design impacts the ability of the human to perform) needs to be considered and may require adjustment to the values. The bodyweight metric for lower body strength (i.e., deadlift) is used in the Army Combat Fitness Testing battery and was identified as a generalizable measurement. The lower body strength standard for unaided egress is consistent with a calculated strength threshold using a previously published relationship between isometric midthigh pull and deadlift (De Witt et al. 2018) along with midthigh pull data collected during simulated space exploration tasks (Ryder 2019). The metric for upper body strength (i.e., bench press) is based on values reported in military populations and also utilizing data from Ryder 2019.]

Table 4.6-1—Pre-Mission Muscle Strength

	Minimum	Microgravity EVAs	Extraterrestrial Surface EVAs	Unaided Terrestrial Egress
Deadlift	1.0 x Body Weight	1.3 x Body Weight	1.6 x Body Weight	1.3 x Body Weight
Bench Press	0.7 x Body Weight	0.8 x Body Weight	1.0 x Body Weight	0.7 x Body Weight

4.6.2 In-Mission Skeletal Muscle Strength

[V1 4024] Countermeasures **shall** maintain in-mission skeletal muscle strength at or above 80% of baseline values.

[Rationale: A relative permissible loss of muscle strength standard was established for maintenance of overall musculoskeletal heath. The Cromwell et al 2019 70-day bedrest study used mission-like ISS exercise equipment capability during long-duration bed rest as spaceflight exercise analog and demonstrated improvements in VO_{2max} and muscle power. The 80% minimum was determined using historical (including ISS) study data showing decrements up to 20% do not impair mission objectives and can be reconditioned to pre-flight muscular strength during post-flight reconditioning (NASA Human Research Program HRP-47072 Evidence Report: Risk of Impaired Performance Due to Reduced Muscle Mass, Strength, and Endurance). This requirement is in addition to the performance-based requirement [V1 4023] Pre-Mission Muscle Strength and Function. Both the relative and performance-based requirements are to be considered when resistance exercise countermeasure capabilities are included in space systems.]

4.6.3 Post-Mission Muscle Reconditioning

[V1 4025] Post-mission reconditioning **shall** be aimed at returning to baseline muscle strength.

[Rationale: Lower body muscle cross-sectional area and strength can be decreased by approximately 10–30% after spaceflight depending on duration and conditions (NASA Human Research Program HRP-47072) Evidence Report: Risk of Impaired Performance Due to Reduced Muscle Mass, Strength, and Endurance). Crewmembers follow program reconditioning guidelines, (per [V1 6009] Medical and Crew Health Technical Requirements Document)); strength is evaluated within 5-7 days of landing, and crewmembers are provided with a daily schedule of prescribed aerobic and strength reconditioning exercises, to enable them to return to pre-mission strength. They are tested at pre-determined intervals to confirm reconditioning success. Further studies are taking place and will continue to inform these prediction numbers.]

4.7 Permissible Outcome Limit for Microgravity-Induced Bone Mineral Density (BMD) Loss

Crewmembers experience decrements in bone mineral density (BMD) during long-duration spaceflight. These changes are concerning due to increased susceptibility to fracture when an external load or unexpected load is applied. These risks could be elevated for longer duration spaceflights where crewmembers may be exposed to microgravity for more than a year. Additional concern is the fact that not all the BMD lost during spaceflight is regained, increasing risk for early onset osteoporosis and fracture risk later in life. Uncertainty still exists regarding changes during spaceflight in BMD, bone structure, and bone microarchitecture, and how these changes might influence fracture risk. In addition to the loss of bone mineral density, it's worth noting that hypercalciuria associated with perturbed bone remodeling can also contribute to the risk of developing renal stones. This is particularly important to consider as the mission impact of renal stones may be higher than that of the BMD loss alone. Changes in bone mineral density with spaceflight and with aging have been well characterized in the crewmember cohort. Longitudinal monitoring of BMD is utilized to assess declines in response to in-flight countermeasures such as exercise and pharmaceuticals.

4.7.1 Pre-Mission Bone Mineral Density

[V1 4026] Crewmembers' pre-mission bone mineral density (BMD) T-scores for total hip and lumbar spine (L1-L4), as measured by mass dual energy X-ray absorptiometry (DXA) **shall** be consistent with an age, sex, gender, and ethnic-matched population.

4.7.2 In-Mission Bone Countermeasures

[V1 4027] Countermeasures **shall** maintain bone mineral density of the hip and spine at or above 95% of pre-mission values and at or above 90% for the femoral neck.

[Rationale: Countermeasures, including an advanced resistive exercise device (ARED), cycle ergometer device, and treadmill, have resulted in the majority of crewmembers returning with <10% deficit bone mineral density in femoral neck and <5% in total hip or spine during 6-month

ISS missions. Additional countermeasures may also include pharmacological antiresorptive (bisphosphonate) therapy which has been tested in research space studies and decreased the bone loss further (~0% loss) when used in combination with exercise countermeasures. Post-mission long-term effects to bone health are being monitored.]

4.7.3 Post-Mission Bone Reconditioning

[V1 4028] Post-mission reconditioning **shall** be aimed at returning bone mineral density to pre-mission baseline values.

4.8 Space Permissible Exposure Limit for Spaceflight Radiation Exposure

The following technical requirements define the Space Permissible Exposure Limits (PELs) for the following: crewmember total career exposure limits, short-term acute exposure limits, and nuclear technology exposure limits. It is important to further minimize exposure from all sources of radiation below the following limits using the As Low As Reasonably Achievable (ALARA) principle. Refer to NASA-STD-3001 Volume 2 section 6.8.1 Ionizing Radiation for vehicle design technical requirements.

4.8.1 As Low as Reasonably Achievable (ALARA) Principle

[V1 4029] All crewmember radiation exposures **shall** be minimized using the ALARA principle.

[Rationale: It is important to minimize crewmember health risk due to radiation exposure by decreasing crewmember radiation exposure from all sources using the ALARA principle. The ALARA principle is a fundamental guiding principle for radiation protection which requires programs to minimize radiation exposures below the limits/technical requirements within the design constraints of the mission.]

4.8.2 Career Space Permissible Exposure Limit for Spaceflight Radiation

[V1 4030] An individual crewmember's total career effective radiation dose due to spaceflight radiation exposure **shall** be less than 600 mSv. This limit is universal for all ages and sexes.

Note: The NASA effective dose for determining the threshold limit is calculated using the NASA Q (based on the NASA cancer model of 2012 as referenced in Human Health and Performance Risks of Space Exploration Missions Evidence Book 2009), 35-year-old female model parameters (tissue weighting factors, phantom etc.), for both males and females. Individual crewmember REID calculations are calculated using the appropriate NASA Q (based on the NASA cancer model of 2012) sex and age model parameters.

[Rationale: For background on setting the limit for this standard, refer to National Academies of Sciences, Engineering, and Medicine 2021. Space Radiation and Astronaut Health: Managing and Communicating Cancer Risks. Washington, DC: The National Academies Press. https://doi.org/10.17226/26155. The total career dose limit is based on ensuring each crewmember (inclusive of all ages and sexes) remains below 3% mean risk of cancer mortality (risk of exposure-

induced death (REID)) above the non-exposed baseline mean. 3% was chosen due to being in the family of individual lifestyle changes (e.g., smoking, lack of exercise). Individual crewmember career dose includes all past spaceflight radiation exposures, plus the projected exposure for an upcoming mission. Medical and biomedical research exposures are not included in the dose limit but are tracked for overall crewmember exposure history. This technical requirement protects the career limits for all organs in Table 4.8-1—Dose Limits for Career/Non-Career Effects (in mGy-Eq or mGy), and Table 4.8-2—Relative Biological Effectiveness (RBE) for Non-Cancer Effects of the Lens, Skin, BFO, and Circulatory Systems, using mGy-eq calculations. All crewmember radiation exposures are to be minimized using the ALARA principle as referenced in [V1 4029] As Low as Reasonably Achievable (ALARA). Due to variability and subjectivity of the selection of model parameters that can easily modify the model output by 25%,, the model need not be updated unless new data indicates a 30% change is seen in the effective dose associated with the 3% mean REID calculation. Refer to NASA/TP-2020-5008710, Ensemble Methodologies for Astronaut Cancer Risk Assessment in the face of Large Uncertainties.]

Table 4.8-1—Dose Limits for Career/Non-Cancer Effects (in mGy-Eq. or mGy)

Note: RBEs for specific risks are distinct as described below.

Organ	***30-DayLlimit***	***1-Year Limit***	***Career***
Lens[#]*	*1,000 mGy-Eq*	*2,000 mGy-Eq*	*4,000 mGy-Eq*
Skin[#]	*1,500 mGy-Eq*	*3,000 mGy-Eq*	*6,000 mGy-Eq*
Blood-forming Organs[#]	*250 mGy-Eq*	*500 mGy-Eq*	*Not applicable*
*Circulatory System**[##]*	*250 mGy-Eq*	*500 mGy-Eq*	*1000 mGy-Eq*
*Central Nervous System***[##]*	*500 mGy*	*1,000 mGy*	*1,500 mGy*
*Central Nervous System*** (Z≥10)[##]*	-	*100 mGy*	*250 mGy*

**Lens limits are intended to prevent early (<5 years) severe cataracts, e.g., from a solar particle event. An additional cataract risk exists at lower doses from cosmic rays for sub-clinical cataracts, which may progress to severe types after long latency (>5 years) and are not preventable by existing mitigation measures; however, they are deemed an acceptable risk to the program.*
***Circulatory system doses calculated as average over heart muscle and adjacent arteries.*
****Central Nervous System limits are to be calculated at the hippocampus.*
#Reference: National Council on Radiation Protection and Measurements. 2000. Recommendations of Dose Limits for Low Earth Orbit. NCRP Report 132, Bethesda MD.
Human Research Program Evidence Book 2009.
Human Research Program Space Radiation Program Element Risk *Evidence book* of Acute and Late Central Nervous System Effects from Radiation Exposu*re 2016*

Table 4.8-2—Relative Biological Effectiveness (RBE) for Non-Cancer Effects[a] of the Lens, Skin, BFO, and Circulatory Systems, used for mGy-eq calculations

Radiation Type	*Recommended RBE* [b]	*Range*
1 to 5 MeV neutrons	*6.0*	*(4-8)*
5 to 5o MeV neutrons	*3.5*	*(2-5)*
Heavy Ions	*2.5* [c]	*(1-4)*
Protons > 2 MeV	*1.5*	-

[a] RBE values for late deterministic effects are higher than for early effects in some tissues and are influenced by the doses used to determine the RBE
[b] There are not sufficient data on which to base RBE values for early or late effects by neutrons of energies <1 MeV or greater than about 25 MeV.
[c] There are few data for the tissue effects of ions with a Z>18, but the RBE values for iron ions (Z=26) are comparable to those of argon (Z=18). One possible exception is cataract of the lens of the eye because high RBE values for cataracts in mice have been reported.
Reference: National Council on Radiation Protection and Measurements. 2000. Recommendations of Dose Limits for Low Earth Orbit. NCRP Report 132, Bethesda MD

4.8.3 Radiation Limits – Solar Particle Events

[V1 4031] The program **shall** protect crewmembers from exposure to the design reference Solar Particle Event (SPE) environment proton energy spectrum (sum of the October 1989 events) to less than an effective dose of 250 mSv.

[Rationale: The 250 mSv effective dose threshold was chosen to minimize acute effects and protects for the limits for all organs listed in Table 4.8-1 Dose Limits for Career/Non-Cancer Effects (in mGy-Eq. or mGy). In the design process, ALARA ensures optimization of the design to afford the most protection possible within other constraints of the vehicle systems. The additional protection significantly contributes to the mitigation of long-term health effects such as cancer (refer to [V1 4030] Career Space Permissible Exposure Limit for Spaceflight Radiation).

Table 4.8-3 contains the Design Reference SPE Environment Proton Energy Spectrum. SPE shielding is to be an inherent part of the vehicle design and/or reconfigured components within the vehicle to minimize the addition of mass. To be most effective, it is critical that the shielding surrounds the crew. The design solution which includes considerations for the vehicle/habitat needs to minimize exposure as much as possible utilizing the ALARA principle. For SPE shielding designs, an iterative approach is to be taken for determining shielding designs that continue to iterate the design until less than a 10 mSv is achieved from the previous iteration. If a reconfigurable shelter is deployed, Environmental Control Life Support System (ECLSS) impacts need to be considered. Refer to Table 4.8-4—Recommended Shielding Guidelines for SPEs, for shielding recommendations based on mission duration and location.]

Table 4.8-3—Design Reference SPE Environment Proton Energy Spectrum (Sum of the October 1989 Events)

Energy (MeV)	Proton Fluence (#/cm²-MeV)	Energy (MeV)	Proton Fluence (#/cm²-MeV)	Energy (MeV)	Proton Fluence (#/cm²-MeV)	Energy (MeV)	Proton Fluence (#/cm²-MeV)	Energy (MeV)	Proton Fluence (#/cm²-MeV)
1.000E-02	7.761E+14	5.770E-01	3.651E+11	4.810E+00	9.004E+09	3.426E+01	1.641E+08	2.484E+02	5.714E+05
1.338E-02	4.329E+14	6.480E-01	2.979E+11	5.317E+00	7.510E+09	3.775E+01	1.298E+08	2.756E+02	4.006E+05
1.790E-02	2.424E+14	7.263E-01	2.442E+11	5.875E+00	6.257E+09	4.160E+01	1.022E+08	3.060E+02	2.773E+05
2.391E-02	1.369E+14	8.129E-01	2.008E+11	6.490E+00	5.208E+09	4.584E+01	8.008E+07	3.407E+02	1.862E+05
3.183E-02	7.805E+13	9.086E-01	1.655E+11	7.168E+00	4.330E+09	5.052E+01	6.136E+07	3.794E+02	1.230E+05
4.210E-02	4.531E+13	1.014E+00	1.368E+11	7.914E+00	3.594E+09	5.568E+01	4.700E+07	4.232E+02	8.060E+04
5.511E-02	2.697E+13	1.130E+00	1.135E+11	8.736E+00	2.979E+09	6.137E+01	3.600E+07	4.728E+02	5.236E+04
7.112E-02	1.657E+13	1.258E+00	9.421E+10	9.641E+00	2.465E+09	6.765E+01	2.754E+07	5.291E+02	3.367E+04
9.027E-02	1.055E+13	1.400E+00	7.839E+10	1.064E+01	2.035E+09	7.460E+01	2.103E+07	5.930E+02	2.141E+04
1.125E-01	6.989E+12	1.556E+00	6.527E+10	1.174E+01	1.677E+09	8.226E+01	1.603E+07	6.665E+02	1.337E+04
1.375E-01	4.810E+12	1.729E+00	5.441E+10	1.294E+01	1.379E+09	9.074E+01	1.219E+07	7.505E+02	8.141E+03
1.657E-01	3.411E+12	1.919E+00	4.541E+10	1.427E+01	1.131E+09	1.001E+02	9.237E+06	8.471E+02	4.859E+03
1.968E-01	2.489E+12	2.129E+00	3.792E+10	1.574E+01	9.248E+08	1.105E+02	6.966E+06	9.588E+02	2.856E+03
2.303E-01	1.872E+12	2.361E+00	3.168E+10	1.735E+01	7.542E+08	1.220E+02	5.234E+06	1.091E+03	1.633E+03
2.675E-01	1.428E+12	2.617E+00	2.647E+10	1.913E+01	6.132E+08	1.348E+02	3.908E+06	1.244E+03	9.199E+02
3.082E-01	1.108E+12	2.900E+00	2.213E+10	2.108E+01	4.969E+08	1.490E+02	2.902E+06	1.418E+03	5.152E+02
3.525E-01	8.711E+11	3.211E+00	1.850E+10	2.323E+01	4.013E+08	1.648E+02	2.134E+06	1.625E+03	2.802E+02
4.010E-01	6.929E+11	3.555E+00	1.546E+10	2.561E+01	3.229E+08	1.824E+02	1.560E+06	1.869E+03	1.486E+02
4.542E-01	5.560E+11	3.933E+00	1.292E+10	2.822E+01	2.588E+08	2.018E+02	1.131E+06	2.158E+03	7.696E+01
5.126E-01	4.493E+11	4.350E+00	1.079E+10	3.109E+01	2.065E+08	2.239E+02	8.074E+05	2.500E+03	3.891E+01

Table 4.8-4—Recommended Shielding Guidelines for SPEs

Mission Location and Duration	***Shielding****	***Type(s) of Shielding***	***Comments***
Celestial surface, any duration	*10 cm (or g/cm²) water equivalent surrounding the crewmember. Considers celestial surface shielding contribution*	*Reconfigurable shielding already within the vehicle*	*Timeline of SPEs allows for reconfiguration*
Beyond low earth orbit <6 months	*15 cm (or g/cm²) water equivalent surrounding the crewmember*	*Reconfigurable shielding already within the vehicle. Shielding may include personal protective equipment (PPE)*	*Timeline of SPEs allows for reconfiguration*
Beyond low earth orbit > 6 Months	*20 cm (or g/cm²) water equivalent surrounding the crewmember*	*Integrated vehicle and/or reconfigurable Shielding which may include PPE*	*Long duration missions increase the probability of the crew being exposed SPEs*
**The shielding required to meet the technical requirement (utilizing existing mass when feasible).*			

4.8.4 Crew Radiation Limits for Nuclear Technologies

[V1 4032] Radiological exposure from nuclear technologies emitting ionizing radiation to crewmembers (e.g., radioisotope power systems, fission reactors, etc.) **shall** be less than an effective dose of 20 mSv per mission year (prorated/extrapolated to mission durations) utilizing the ALARA principle.

[Rationale: This limit is based on adding no more than 10% radiation exposure beyond the space environment radiation of the mission. Based on an analysis for a surface-based mission (see Figure 4.8-1 Ronald E. Turner (2022) Impact of Solar Cycle Duration on Astronaut Radiation Exposure during a Human Mars Mission), the radiation environment exposure is approximately 0.5 mSv per day; and 10% of this value sets the technical requirement to 0.05 mSv per day and ~20 mSv/mission year. This technical requirement is applied to both surface and free-space missions regardless of mission solar cycle. 20 mSv is also based on the occupational workers limit guideline from the ICRP, (The 2007 Recommendations of the International Commission on Radiological Protection, ICRP 103, 2007).

For a typical surface power application, the allowable crewmember dose can be converted to an effective reactor dose for shield sizing. The effective reactor dose would be calculated by estimating the time a crewmember spends in a shielded habitat versus the time spent during unshielded EVAs over a typical mission timeline. Exact mission assumptions need to be considered when performing the calculation; parameters are to include estimates of time in a habitat, habitat shielding, and EVA frequency. Example parameters to be considered: time fraction (67%) in the habitat, habitat shielding (20 g/cm2), terrain shielding, distance from source, line of sight to source, and time fraction (33%) of performing EVAs.

Space radiation and radioactive source tradeoff for a waiver of technical requirement consideration: For missions that are leveraging nuclear sources for a propulsion system, the tradeoff of reduced mission duration due to faster transit, which reduces the crew exposure to spaceflight radiation, is to be considered compared to the increased exposure due to the nuclear source. For example, if the nuclear propulsion system saves 90 days of exposure over a one year transit to Mars (which equates to 1.5 mSv/day × 90 days = 135 mSv "saved" spaceflight radiation exposure) and the source generates 150 mSv, then the net exposure is +15 mSv. Other considerations for reduced mission time on engineering risks (systems reliability, logistics, etc.) and other human risks such as bone loss, renal stone development, and medical care is to be considered in the waiver process.]

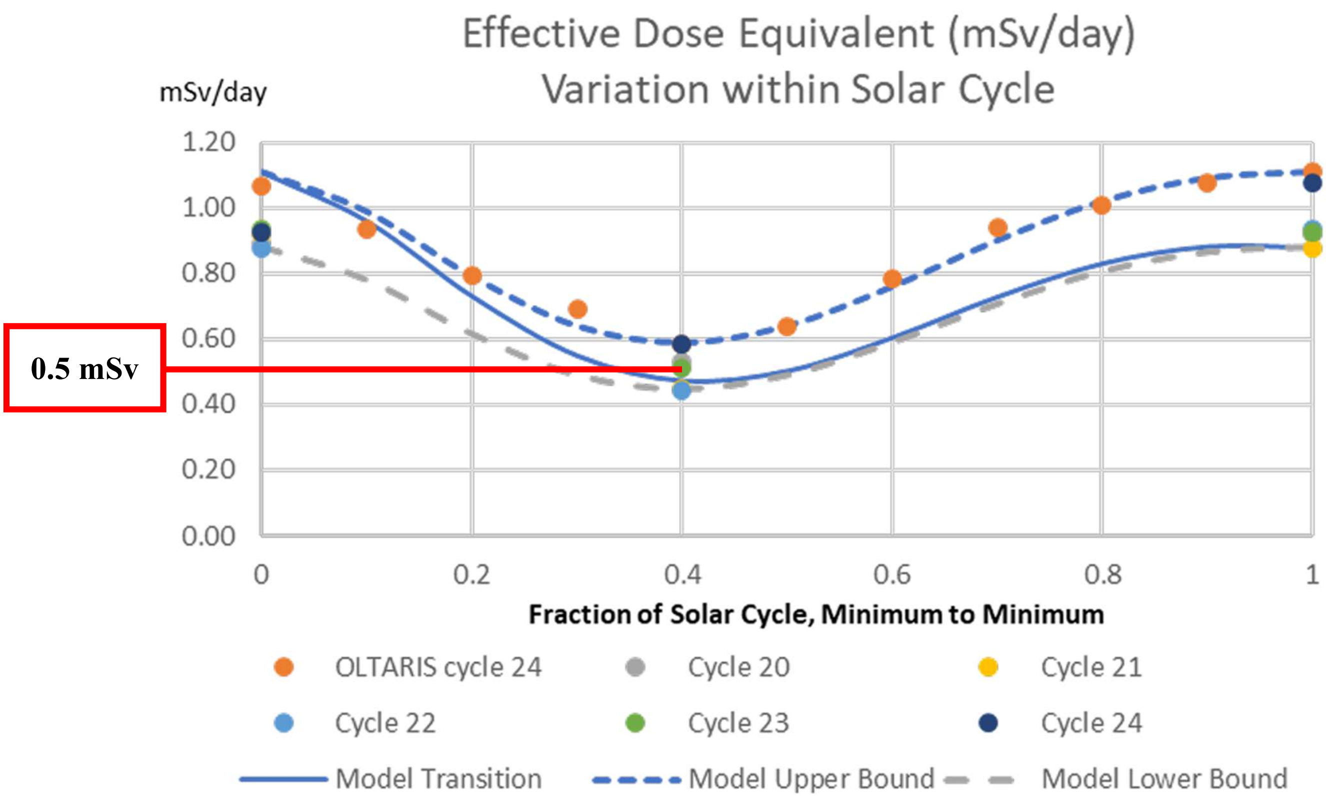

Figure 4.8-1—Effective Dose (mSv per Mission Day) Variation with Solar Cycle

4.8.5 Crew Radiation Limits from Galactic Cosmic Radiation

[V1 4033] For habitable space systems designed to support crew for > 60 days, the program **shall** protect crewmembers from exposure to the galactic cosmic ray (GCR) environment to less than a NASA effective dose (as defined in NASA-STD-3001, Volume 1 [V1 4030] Career Space Permissible Exposure Limits for Spaceflight Radiation) rate of 1.3 mSv/day for systems in free space and to less than 0.9 mSv/day for systems on planetary surfaces.

Note: To verify the habitable space system design meets the GCR protection requirement above, the NASA effective dose rate is calculated using the 2009 solar minimum Badhwar O'Neill GCR model spectrum and take into account estimated crew time spent at lightly and more heavily shielded locations throughout the habitable space system. If achievable, further measures are to be taken to reduce crew exposure in accordance with the ALARA principle, as set forth in [V1 4029] As Low as Reasonably Achievable (ALARA) Principle.

[Rationale: This requirement applies to missions beyond Low-Earth orbit. For these missions, vehicle and habitat systems need to be designed to provide sufficient protection to reduce exposure from GCR by at least 15% in free space and by at least 10% on the lunar surface. The 60-day minimum is designated to protect crewmembers beyond short duration initial capability missions. This ensures risks are minimized while maximizing spaceflight opportunities for crewmembers within the limits set forth in [V1 4029] As Low as Reasonably Achievable (ALARA) Principle and

[V1 4030] Career Space Permissible Exposure Limits for Spaceflight Radiation. The design reference environment is the 2009 solar minimum spectrum as described by the Badhwar O'Neill 2020 GCR Model. During solar minimum, vehicle shielding can effectively reduce the free space, unshielded GCR effective dose rate of 1.5 mSv/day by approximately 15% to 1.3 mSv/day or lower depending on the vehicle/shielding materials incorporated into vehicle design. While shielding against the build-up of secondary neutrons on the lunar surface is more challenging, reductions of 10% can be effectively realized for lunar surface systems. Reductions can be achieved with shielding density thickness between 10-40 g/cm^2. Further reductions to effective dose are difficult to realize given the fact that shield density thickness between 40-100 g/cm^2 have either a negligible or negative impact on the exposure rate, while potentially introducing a significant mass/launch burden. Additional shielding on the Mars surface is likely not beneficial unless hydrogenous materials are incorporated for long duration stays.]

5. TRAINING

The following technical requirements outline the required training for personnel who support a spaceflight mission including but not limited to NASA personnel, International Partners, and commercial providers.

5.1 Medical Training

[V1 5001] Medical training **shall** be provided to crewmembers, flight surgeons (FSs), mission control support staff, and other ground support personnel (GSP).

[Rationale: Crewmembers, flight surgeons (FSs), mission control support staff, and other ground support personnel will encounter a variety of situations, from launch to landing, that will require medical training including, but not limited to: basic first aid and CPR ,basic health, behavioral health, and medical operations including medical kit utilization, space medicine (altitude, carbon dioxide exposure, decompression sickness and pressure effects) training, toxic exposure (e.g. ammonia), and emergency medical interventions. This training will vary depending on DRM, mission duration, personnel number, and expertise.]

5.2 Crewmember Training

[V1 5002] Beginning with the crewmember candidate year, general medical training, including but not limited to, first aid, cardiopulmonary resuscitation (CPR), altitude physiological training, carbon dioxide exposure training, familiarization with medical issues, procedures of spaceflight, psychological training, toxicology, medical equipment, and supervised physical conditioning training **shall** be provided to the astronaut corps.

[Rationale: Crewmembers begin medical training, starting their candidate year, to enable them to care for themselves and other crewmembers during missions. Training includes but is not limited to, basic first aid and CPR, basic health, behavioral health, and medical operations including medical kit utilization, space medicine (altitude, carbon dioxide exposure, decompression sickness and pressure effects) training, toxic exposure (e.g., ammonia), exercise countermeasures, and emergency medical interventions. Training depends on DRM, mission duration, personnel number, and crewmember expertise.]

5.2.1 Crew Medical Officer Medical Training

[V1 5003] Crewmembers who have received a mission assignment as a Crew Medical Officer (CMO) **shall** be provided with detailed and specific medical training, including but not limited to, health issues, space physiology, behavioral health, medical procedures, medical equipment, toxicology, and countermeasures.

[Rationale: Crew Medical Officer refers to a crewmember who has been assigned as a medical expert for a particular mission. CMOs often are, but are not required, to be physicians. CMOs receive more specific training including but not limited to: detailed general health training, behavioral health, human physiology, treatment for health events with increased risk, treatment of

risks specific to space (space physiology) including but not limited to: kidney stones, SANS, effects of altitude, pressure, CO_2 exposure, medical procedures, and techniques (i.e., ultrasound, cardio equipment, hematology monitoring, toxicology, and countermeasures).]

5.2.1.1 Crew Medical Officers Quantity

[V1 3006] The program(s) **shall** train a minimum of two crewmembers per vehicle/platform as Crew Medical Officers (CMOs).

[Rationale: It is critical to have two CMOs for each vehicle/platform to ensure that a backup is available for medical treatment. Additional considerations are needed for missions that include multiple vehicles and varying locations. For example, if a vehicle launches with an initial crew complement and then part of that crew complement leaves for another destination, then it is critical that two CMOs are available at each location. Depending on total mission design, this may require more than two CMOs to be launched on a vehicle. Additionally, all other crewmembers become familiar with the use of in-mission medical equipment and protocols. This can be further facilitated by choosing equipment that is designed for ease of use.]

5.2.2 Medical Training Verification

[V1 5004] Medical Training **shall** be verified for all personnel.

[Rationale: Crewmembers and all associated personnel, including ground crew, have a training plan and completion record. Documented training plans are necessary and used to determine personnel readiness to support the mission. The level of training required varies by position, role, and DRM. New training programs may vary but are to have intent consistent with well-established programs, satisfy the established training requirements, and be verifiable.]

5.3 Flight Surgeon Training

[V1 5005] Flight Surgeons, including but not limited to NASA and International Partners, assigned to support the subject space program **shall** receive training and certification in accordance with a program-specific training plan.

[Rationale: For the subject program, this training includes courses such as mission controller certification (for all involved Mission Control Centers), advanced cardiac life support/advanced trauma life support (ACLS/ATLS), flight medicine procedures, aerospace physiology, space medicine, hyperbaric medicine, and emergency mishap response. An example is JSC-26546, NASA International Space Station Flight Surgeon Training and Certification Plan.]

5.4 Medical Operations Flight Controller Training

[V1 5006] All Medical Operations personnel staffing the Mission Control Center (MCC) **shall** be trained and certified according to program-specific training and certification plans.

[Rationale: Flight control personnel have a training plan and completion record including recertification at proper intervals, to determine personnel readiness to support the mission. The level of training required varies by position, role, and DRM. New training programs may vary but are to have intent consistent with well-established programs, satisfy the established training requirements, and be verifiable.]

5.5 Support Personnel Training

[V1 5007] Supervised training programs **shall** be implemented for individuals including but not limited to NASA personnel, International Partners, and commercial/private space programs, who require knowledge of space medicine or flight medical procedures, such as flight directors, medical consultants, and/or other personnel deemed appropriate as part of the Medical and Crew Health Technical Requirements Document.

[Rationale: Support personnel have a training plan and completion record to determine personnel readiness to support the mission. The level of training required varies by position, role, and DRM. New training programs may vary but are to have intent consistent with well-established programs, satisfy the established training requirements, and be verifiable.]

5.6 Psychological Mission Training

[V1 5008] Specific pre-mission briefings and training **shall** be provided as appropriate to the commander (CDR), CMOs, crewmembers, key ground personnel, and crew families concerning the significant psychological and social phenomena that may arise in all phases of a mission.

[Rationale: This training may include the following:

a. Provision of recommendations and guidelines for family support activities.

b. Training and support for effective individual adaptation, crew integration, and team dynamics.

c. Training for medical and other GSP as indicated in support of behavior and performance issues.

d. Cross-cultural training and support as indicated for international missions.

e. Palliative and mortality incidents.]

5.7 Physiological Exposure Mission Training

[V1 5009] Physiological training **shall** be provided to assist crewmembers with pre-mission familiarization to in-flight exposures including but not limited to: carbon dioxide [CO_2] exposure training, hypoxia training/instruction, centrifuge, and high-performance aircraft microgravity adaptation training in preparation for each mission.

[Rationale: Familiarity with the space environment, including atmospheric conditions and factors that may affect human performance, increases awareness of potential risks and improves the ability of a crewmember to mitigate such risks. Training tailored to specific vehicular considerations, such as hypergravity profile and onboard atmospheric parameters, further increases operational performance and the likelihood of mission success.]

6. MEDICAL OPERATIONS

The term "space medicine operations" refers to the activities of clinicians, health care professionals, scientists, and engineers who support crewmember health and performance during their training and spaceflight. Examples of such activities include preparing for medical emergencies, monitoring the use of biomedical hardware, and providing longitudinal clinical care. Stressors unique to spaceflight, such as microgravity and galactic cosmic radiation, as well as more familiar stressors, such as isolation and fatigue, can each contribute to changes in human health and physiology.

6.1 Circadian Shifting Operations and Fatigue Management

[V1 6001] Crew schedule planning and operations **shall** be provided to include circadian entrainment, work/rest schedule assessment, task loading assessment, countermeasures, and special activities.

[Rationale: Crew schedule is to be established to ensure protection of crew physical and mental health while working to meet mission goals. Maintaining circadian entrainment (alignment between a crewmember's body clock and work/rest schedule) is critical to ensure crew are able to sleep during the designated sleep opportunity. Circadian entrainment requires consistent timing of sleep opportunities from one day to the next. Crew schedule considerations include, but are not limited to:

a. Crew on/off duty daily limits

b. Cumulative crew workload limits

c. Recommended 8.5 hr. sleep period (need to also include pre sleep of 2 hrs./post sleep of 1.5 hrs.)

d. Avoid scheduling critical tasks during nominal sleep period

e. Avoid scheduling critical tasks during the circadian nadir (typically between 1-7 AM relative to one's regular sleep schedule) especially before/after launch/docking/undocking/landing.

f. Fatigue management (evaluation and assessment)

g. Integrate, including time to facilitate, countermeasures for sleep shifting, fatigue, and sleep issues (e.g., light, naps, and pharmaceutical/non-pharmaceutical)

h. Individual variability (slam/gradual shifting)

i. Launch/dock/undock/landing awake requirements

j. Space adaptation]

6.2 Private Medical Communication

6.2.1 Private Medical Communication Schedule

[V1 6002] Private medical communications **shall** be scheduled on a routine basis, as determined by the Flight Surgeon, at a frequency dictated for short- or long-duration missions.

[Rationale: Real time communications are preferred for all private medical communications, however when missions have communication delays, different modalities can be considered (e.g., stored/forward communications).]

6.2.2 Private Medical Communications Information Delivery

[V1 6003] Private Medical Communications information that is sent to/from the ground via spacecraft communication systems **shall** be considered private communication.

[Rationale: This private communication provides for privacy of medical information between the crewmembers and the appropriate health and medical personnel per the Privacy Act of 1974.]

6.3 Behavioral Health and Performance

Behavioral Health and Performance includes the ability to control and facilitate a range of psychological responses to environments or stressors, allowing for adaptation. Factors that may alter psychological response include heavy workload, physical and psychological separation from home and support systems, altered circadian cycles, as well as environmental factors such as microgravity, altered atmospheric environments, and gravity transitions. Each of these factors may adversely affect mood, behavior, cognition, and performance. Stressors associated with a space mission extend to ground and support personnel and crew families. This section identifies requirements for providing psychological support programs for crew, families, and key ground personnel.

6.3.1 Behavioral Health and Performance Programs

[V1 6004] Programs **shall** implement psychological/behavioral health support programs for the crewmembers, key ground personnel, and crewmember families throughout the mission.

[Rationale: The provisions may include but are not limited to the following:

a. Recommendations and guidelines for family support activities.

b. Support for effective individual adaptation, crew integration, and team dynamics.

c. Recommendations to crew selection entities, as requested, to assist in crew assignment and composition.

d. Medical and other GSP as indicated in support of behavior and performance issues.

e. *Cross-cultural support as indicated for international missions.]*

Deleted.

Requirement [V2 6005] deleted.

6.3.2 Psychological Communication

6.3.2.1 Private Psychological Communication (PPC) Schedule

[V1 6010] A PPC **shall** be scheduled on a routine basis, as determined by the Behavioral Health Provider, at a frequency dictated for short- or long-duration missions.

[Rationale: PPCs conducted as real-time communication constitute an important element of Medical Support and have already been implemented as medical requirement for ISS operations in addition to private medical communications. However, when missions have communication delays, different modalities can be considered (e.g., stored/forward communications.]

6.3.2.2 Psychological Communications Information Delivery

[V1 6011] Psychological information that is sent to/from the ground via spacecraft communications systems **shall** be considered private communication.

[Rationale: The Private Psychological Communication (PPC) deals directly with psychological issues. It must be ensured that all information is treated analog to private medical information.]

6.4 Extravehicular Activities (EVAs)

[V1 6006] All crewmembers **shall** be medically cleared to perform an EVA by ground medical support personnel prior to each EVA.

[Rationale: EVA crewmembers are evaluated for their health status and fitness levels prior to EVAs. Flight Surgeon on ground evaluates available data from recent medical evaluations, fitness sessions, and other metrics of health and performance to determine readiness for EVA.]

Deleted.

Requirement [V1 6007] merged into [V1 3004].

6.5 Crew Health Operations Concept (CHOC)

6.5.1 Crew Health Operations Concept Document

[V1 6008] The program(s) **shall** develop a crew health concept of operations document to define the medical and health care concepts during all phases of the spaceflight program.

[Rationale: The medical and health care operations concept needs to include, at minimum, the operational concepts of crew selection; preflight medical intervention technical requirements; in-flight medical and health care technical requirements; private medial conferences; periodic health and fitness evaluation; behavioral health support for the crewmember, ground personnel, and crewmember families; definitive care facilities; vehicle/habitat crew performance system; medical survival kits; post- flight technical requirements; post-flight medical evaluations; and landing/launch EMS support. For past programs, this information has been documented in a Crew Health Operations Concept (CHOC) document.]

6.5.2 Medical and Crew Health Technical Requirements Document

[V1 6009] The program(s) **shall** develop a medical and crew health technical requirements document based on the concepts outlined in the program-specific crew health operations concept (CHOC) document and NASA-STD-3001.

[Rationale: The medical and crew health technical requirements document needs to include, at minimum, the implementation of the technical requirements for crew selection; pre-flight medical intervention technical requirements; in-flight medical and health care technical requirements; private medial conferences; periodic health and fitness evaluation; behavioral health support for the crew, ground personnel, and crew families; definitive care facilities; vehicle/habitat crew performance system; crew and ground support training; medical survival kits; post-flight technical requirements; post- flight medical evaluations; and landing/launch EMS support. The Medical and Crew Health Technical Requirements Document ensures effective implementation and communication of the health and medical care for the crew from selection to post-flight reconditioning. For missions beyond LEO that may involve multiple programs, one medical and crew health technical requirements document may include the medical and crew health technical requirements for each program that contributes to the mission (e.g., Artemis). For past programs, this information has been documented in a MORD.

Medical Operations Requirements Document (MORD) details the medical technical requirements for the program and is consistent with the overall crew health operations concepts. A MORD is developed for each program. A crew health operations concept is developed and documented for each program.]

7. CREW HEALTH RECORDS

Crew health records, including medical records, behavioral health records, and physical examination records, are securely maintained, stored, and communicated following agency guidelines. Crew health information is used for a variety of reasons including crewmember knowledge, operational needs, evaluation, and trend analysis. Crew health information is communicated, when necessary, in a timely manner to meet the program operational needs.

7.1 Crew Health Results

[V1 7001] The results of all crew health monitoring **shall** be kept in a permanent retrievable format for evaluation including trend analysis.

[Rationale: These records are required for individual and population evaluation including trend analysis and are to be preserved and accessible.]

7.2 Crew Records Transmission

[V1 7002] The method of transmission of crewmembers' medical health data **shall** meet the medical operational needs of the program.

[Rationale: Crewmembers' medical health data is used in a variety of instances. The most critical need may be when a crewmember is directly engaged in operational activities, and the most up to date medical data is required to meet the medical operational needs of the program.]

7.3 Crew Records Security

[V1 7003] The method for handling, storing, and transmission of crewmembers' medical health records **shall** be secured.

[Rationale: Medical health records contain Personal Identifiable Information (PII) and are to be maintained in a secure fashion so that information about individuals is not disclosed without their consent, per the Privacy Act of 1974 (5 U.S.C. § 552a,).]

APPENDIX A

REFERENCES

A.1 PURPOSE

This Appendix provides references to guidance documents related to this NASA Technical Standard. Reference documents may be accessed at https://standards.nasa.gov, obtained directly from the Standards Developing Body or other document distributors, obtained from information provided or linked, or by contacting the Center Library or office of primary responsibility.

A.2 REFERENCE DOCUMENTS

A.2.1 Government Documents

NASA

ICRP 103, 2007	The 2007 Recommendations of the International Commission on Radiological Protection
JSC 26546	NASA International Space Station Flight Surgeon Training and Certification Plan
JSC 27384	Behavioral Health Plan and Performance Plan Definition and Implementation Guide
JSC 67378	Nutritional Requirements for Exploration Missions up to 365 Days
NASA HRP 047072	NASA Human Research Program Evidence Report HRP-047072 The Risk of Reduced Physical Performance Capabilities Due to reduced Aerobic Capacity 2023
NASA HRP 047072	NASA Human Research Program HRP-47072 Evidence Report: Risk of Impaired Performance Due to Reduced Muscle Mass, Strength, and Endurance 2023
NASA-STD-3001,Volume 2	NASA Spaceflight Human System Standard, Volume 2: Human Factors, Habitability, and Environmental Health
NASA/TP-2020-5008710	Ensemble Methodologies for Astronaut Cancer Risk Assessment in the face of Large Uncertainties
NASA TLX	NASA Task Load Index

NASA	
SSP 50480-ANX5	Joint Medical Operations Implementation Plan, Annex 5: Multi-Lateral Medical Operations Panel Guidelines and Procedures for the Response to a Crewmember Fatality In-Flight
SSP 50667 Vol A	Medical Evacuation Documents Volume A Medical Standards for ISS Crewmembers
SSP 50667 Vol B	Medical Evaluation Documents (MED) Volume B-Pre-flight, In-mission, and Post-mission Medical
SSP 50667 Vol C	Evaluation Technical Requirements for Long-Duration ESS Crewmembers Medical Evaluation Documents (MED) Volume C-Medical Standards and Certification Procedures for Space Flight Participants
SSP 51721	ISS Safety Requirements Document
Federal	
Public Law 109-155, Section 821	The NASA Authorization Act of 2005
RES 2222 (XX1)	Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies

A.2.2 Non-Government Documents

Convertino, V.A. (1997). Cardiovascular consequences of bed rest: effect on maximal oxygen uptake. *Med Sci Sports Exerc, 29*(2):191-6. doi: 10.1097/00005768-1997020000-00005.

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European Space Agency Personal Data Protection Policy https://business.esa.int/privacy-policy

ESA/C/CCLXVIII/Res.2, Principles of Personal Data Protection

Human Health and Performance Risks of Space Exploration Missions Evidence Book (2009).

Human Research Program Space Radiation Program Element Risk Evidence book of Acute and Late Central Nervous System Effects from Radiation Exposure 2016

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Ryder, J.W., et al. (2019). A novel approach for establishing fitness standards for occupational task performance. *Eur J Appl Physiol, 119*(7):1633-1648. doi: 10.1007/s00421-019-04152-3.

Scott, J.M., et al. (2023). Effects of exercise countermeasures on multisystem function in long duration spaceflight astronauts. *npj microgravity, 9*(11). doi: 10.1038/s41526-023-00256-5

Slaba, T.C., & Whitman, K. (2020). The Badhwar-O'Neill 2020 GCR model. *Space Weather, 18*.

Space Radiation and Astronaut Health: Managing and Communicating Cancer Risks. Washington, DC: The National Academies Press. https://doi.org/10.17226/26155

Sutterfield, S.L., et al. (2019). Prediction of Planetary Mission Task Performance for Long-Duration Spaceflight. *Medicine and Science in Sports and Exercise, 51*(8): 1662-1670. doi: 10.1249/mss.0000000000001980. PMID: 30882564.

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APPENDIX B

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

B.1 PURPOSE

This Appendix provides guidance, made available in the acronym, abbreviation, and symbol definitions listed below.

B.2 ABBREVIATIONS AND ACRONYMS

%	percent, percentile
ACLS	advanced cardiac life support
ATLS	advanced trauma life support
ASCR	astronaut strength, conditioning, and rehabilitation specialist
ALARA	as low as reasonably achievable
ARED	advanced resistive exercise device
ART	assisted reproductive technology
BFO	blood forming organ(s)
BMD	bone mineral density
CCP	Commercial Crew Program
CDR	commander
CEVIS	cycle ergometer with vibrational isolation and stabilization
CHOC	crew health operations concept
cm	centimeter
CMO	crew medical officer
CO_2	carbon dioxide
COSPAR	Committee for Space Research
CPR	cardiopulmonary resuscitation
DMCF	definitive medical care facility
DOD/DoD	Department of Defense
DRM	design reference mission
DXA	dual energy x-ray absorptiometry
ECLSS	environmental control life support system
EMS	emergency medical services
EMT	emergency medical technician
ETA	estimated time of arrival
	Engineering Technical Authority
EVA	extravehicular activity
FAR	Federal Acquisition Regulation
FOD	Flight Operations Directorate
FFD	fitness for duty
FFRDC	Federally Funded Research and Development Center
FS	flight surgeon
G	gravity

GCR	galactic cosmic rays
GSP	ground support personnel
G-transition	gravity transitions
HEOMD	Human Exploration and Operations Mission Directorate
HIDH	Human Integration Design Handbook
HIDP	Human Integration Design Processes
HMTA	Health and Medical Technical Authority
Hr	hour
HRP	Human Research Program
HSP	Health Stabilization Program
IMM	integrated medical model
ISS	International Space Station
ICRP	International Commission on Radiological Protection and Measurements
IP	International Partner
IV	intravenous
JSC	Johnson Space Center
kcal	kilocalorie(s)
kg	kilogram(s)
LE	lower extremity
LEO	Low-Earth orbit
LET	linear energy transfer
m	meter(s)
max	maximum
MCC	Mission Control Center
MED	medical evaluation documents
MeV	megaelectron volt
mGy	milligray
mGy-Eq	milligray-equivalent
min	minute(s)
ml	milliliter(s)
MORD	Medical Operations Requirements Document
MSFC	Marshall Space Flight Center
mSv	millisieverts
NASA	National Aeronautics and Space Administration
NBL	Neutral Buoyancy Laboratory
NCRP	National Council on Radiation Protection and Measurements
NPD	NASA Policy Directive
NPR	NASA Procedural Requirement
OCHMO	Office of the Chief Health and Medical Officer
OSHA	Occupational Safety and Health Administration
PEL	permissible exposure limit
PMC	private medical communication/conference
POL	permissible outcome limits
PPE	personal protective equipment
PRA	probabilistic risk assessment
PFC	private family conference

PPC	private psychological conference
PRD	program technical requirements document
RBE	relative biological effectiveness
REID	risk of exposure-induced death
RER	respiratory exchange ratio
ROC	receiver operating characteristic
SANS	Spaceflight Associated Neuro-Ocular Syndrome
SARS-CoV-2	severe acute respiratory syndrome coronavirus 2
SAS	Space Adaptation Syndrome
SD	standard deviation
SI	System International or metric system of measurement
SMATA	Safety and Mission Assurance Technical Authority
SPE	solar particle event
SPEL	space permissible exposure limits
SSP	Space Station Program
STD	standard
STS	Space Transportation System
TREAT	To Research, Evaluate, Assess, and Treat
U.S./US	United States
V1	Volume 1
V2	Volume 2
VO	volume of oxygen

APPENDIX C

DEFINITIONS

C.1 PURPOSE

This Appendix provides guidance, made available in the definitions listed below.

C.2 DEFINITIONS

As low as (is) reasonably achievable (ALARA): Making every reasonable effort to maintain exposures to ionizing radiation as far below the dose limits as practical, consistent with the purpose for which the licensed activity is undertaken, taking into account the state of technology, the economics of improvements in relation to state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of nuclear energy and licensed materials in the public interest.

Aerobic Fitness: The ability to perform dynamic exercise that involves large muscle groups at a moderate to high intensity for prolonged periods.

Astronaut: An individual selected and trained to travel into space and to monitor, operate, and control parts of, or the whole space system to complete mission objectives. Also see Crewmember.

Barotrauma: Injuries caused by changes in pressure.

Bisphosphonates: A group of medicines that slows own or prevent bone loss, preserving bone strength.

Bone Mineral Density (BMD): The amount of mineral content per unit volume of bone.

Areal Bone Mineral Density (aBMD): The amount of mineral content per unit area of bone (g/cm^2) which indicates how BMD compares to that of a healthy 30-year-old. Peak bone density is reached by age 30 and ideally be maintained at this level throughout life. As BMD decreases from this peak density, fracture risk could increase. The T-score is in units of standard deviations (SD) and shows whether bones are more dense (+) or less dense (-) than those of a 30 year old. A T-score of -1.0 or above is normal bone density, between -1.0 and -2.5 means low bone density or osteopenia, and a T-score of -2.5 or below is a diagnosis of osteoporosis.

Career Dose: The amount of radiation dose received by a crewmember over the course of their career.

Circadian Misalignment: Desynchronization between the timing of the master circadian pacemaker in the suprachiasmatic nucleus (SCN) of the hypothalamus and sleep wake timing or desynchronization between the SCN and peripheral oscillators, such as those in the gut, liver, and reproductive organs.

Circadian Rhythm: The natural cycle of physical, mental, and behavior changes that the body goes through in a 24-hour cycle.

Cognitive Function: Any mental process that involves symbolic operations. Cognitive function encompasses awareness and capacity for judgment.

Crew: Team of two or more crewmembers assigned to a mission that have been trained to monitor, operate, and control parts of, or the whole space system.

Crew Medical Officer: Crewmember who has been assigned as a medical expert for a particular mission.

Crewmember: An individual member of a crew. Also see Astronaut.

Definitive Medical Care Facility (DMCF): An inpatient medical facility capable of comprehensive diagnosis and treatment of a crewmember's injuries or illness. DMCFs are trauma-capable facilities; ideally, such facilities should be capable of managing (per the American College of Surgeons' definitions) Category I, II, and III trauma patients. In an off-nominal landing location, depending on regional resources, a facility with more limited capabilities may be considered a DMCF if able to manage crewmember medical needs. Interim treatment locations, such as a recovery ship, field triage station, or lower capability medical facility, may be utilized for stabilization until transport to a DMCF is possible.

Depressurization: Reducing the pressure of air or gas within a suit, chamber, or vehicle.

Dual-energy X-ray absorptiometry (DXA): An x-ray-based test that measures bone mineral in a 2D projected image of bone tissue.

Dysbarism: Any adverse medical condition that results from changes in ambient pressure. These changes in pressure must occur either at a rate or duration exceeding the capacity of the body to adapt safely.

Effective Dose: The tissue-weighted sum of the equivalent doses in all specified tissues and organs of the human body and represents the stochastic health risk to the whole body, which is the probability of cancer induction and genetic effects, of low levels of ionizing radiation.

Environmental Control and Life Support (ECLSS): A system designed to distribute air and remove contaminants. The elements include all hardware, software, equipment, facilities, personnel, processes, and procedures needed for this purpose.

Estimated Mission Radiation Dose: Estimated amount of radiation dose for a particular design reference mission category (length of a mission, distance from Earth, etc.).

Exercise: Any bodily activity that enhances or maintains physical fitness and overall health and wellness. Exercise is used to maintain or minimize loss of crewmember muscle mass and cardiovascular fitness, to maintain muscle strength/endurance, for recovery from strenuous tasks and confined postures, to rehabilitate minor muscle injuries, and to maintain bone mass. Exercise also has behavioral health benefits.

Extravehicular Activity: Operations performed by suited crew outside the pressurized environment of a flight vehicle or habitat (during spaceflight or on a destination surface). Includes contingency operations performed inside unpressurized vehicles or habitats.

Fitness for Duty (FFD): Minimum measurable capability or capacity for a given physiological or behavioral parameter that allows successful performance of all required duties.

Free-space: vehicle location is far enough from a celestial body such that the combined effects from terrestrial, atmospheric, and magnetic shielding can be ignored.

Galactic Cosmic Rays (GCR): Originates outside the solar system. It consists of ionized atoms ranging from a single proton up to a uranium nucleus. The flux (rate of flow) levels of these particles is very low. However, since they travel very close to the speed of light, and because some of them are composed of very heavy elements such as iron, they produce intense ionization as they pass through matter.

Gravity Transitions (G-transition): Physiological effects caused by changes in gravitational forces, alternating between hypogravity (<1GZ) and hypergravity (>1GZ).

Hypothermia: A medical emergency that occurs when the body loses heat faster than it can produce heat, causing a dangerously low body temperature. Normal body temperature is around 98.6ºF (37ºC). Hypothermia occurs as your body temperature falls below 95ºF (35ºC).

Hypoxia: A deficiency of oxygen reaching the tissues of the body.

Incapacitation/Crew Rescue: Injuries sustained by a crewmember during an extravehicular activity that prevent the affected crewmember from continuing independent operations, and which would require support from other suited crew to avert mission level outcomes.

In-Mission: All phases of the mission, from launch, through landing on a planetary body and all surface activities entailed, up to landing back on Earth.

Insomnia: Dissatisfaction with sleep quantity or quality, associated with one (or more) of the following symptoms: Difficulty initiating sleep or maintaining sleep, characterized by frequent awakenings or problems returning to sleep after awakenings.

Linear Energy Transfer (LET): The average amount of energy imparted to a material by an ion per unit path length traveled by the ion. The LET of an energetic ion, weighted by a radiation "quality factor," is used in regulatory standards as a relative measure of biological effectiveness for harm resulting from ionizing radiation exposures.

Maximum VO_2 (VO_{2max}): The maximum amount of oxygen the body can utilize during a specified period of usually intense exercise.

Medications: A pharmaceutical or other substance used for medical diagnosis, prevention, or treatment.

Nutrients: Nutrients are substances that provide the body with the nourishment essential for growth and maintenance of life.

Nutrient Deficiencies: Nutrient deficiencies occur when the body is not getting enough nutrients to support normal physiological system function.

Palliative Care: Specialized medical care that focuses on providing patients relief from pain and other symptoms of a serious illness, no matter the diagnosis or stage of disease. Palliative care teams aim to improve the quality of life for both patients and their families.

Permissible Outcome Limits (POL): Acceptable maximum decrement or change in a physiological or behavioral parameter, during or after a spaceflight mission, as the result of exposure to the space environment. Biological/clinical parameter measured, e.g., bone mineral density.

Probabilistic Risk Assessment (PRA): A comprehensive, structured, and disciplined approach to identifying and analyzing risk by seeking answers to three basic questions: what can go wrong, how likely is it, and what are its consequences? (Derived from ESD 10011)

Relative Biological Effectiveness (RBE): A term used to compare how damaging radiation is, using x-rays or gamma rays as a reference. A radiation that is 10 times more effective per unit dose than X-rays would have an RBE of 10. RBE varies with dose, dose rate, and measured endpoint among other factors.

Schedule: Arrange, control, and optimize work and workloads to facilitate crew timeline of activities.

Sievert: A derived (not directly measured) unit of dose equivalent or NASA equivalent dose of radiation which accounts for the biological effect (radiation quality and tissue sensitivity) of ionizing radiation in reference to carcinogenic potential. 1 Sv = 1000 millisieverts (mSv).

Solar Particle Event (SPE): Injections of energetic electrons, protons, alpha particles, and heavier particles into interplanetary space. These particles are accelerated to near relativistic speeds by the interplanetary shock waves which precede fast coronal mass ejections, and which exist in the vicinity of solar flare sites. The most energetic particles arrive at Earth within tens of minutes of the event on the Sun, while the lower-energy population arrives over the course of a day. They temporarily enhance the radiation in interplanetary space around the magnetosphere, and they may penetrate to low altitudes in the polar regions.

Space Permissible Exposure Limits (SPEL): Quantifiable limit of exposure to a spaceflight factor over a given length of time, e.g., lifetime radiation exposure.

Space System: The collection of all space-based and ground-based systems (encompassing hardware and software) used to conduct space missions or support activity in space, including, but not limited to, the crewed space system, space-based communication and navigation systems, launch systems, and mission/launch control. Also referred to as "system" in the technical requirements.

TREAT (To Research, Evaluate, Assess, and Treat) Astronauts Act: Authorizes NASA to monitor and diagnose potential conditions and treat conditions associated with spaceflight. It is a comprehensive program of monitoring, diagnosis, and treatment services provided to current and former United States Government astronauts.

Toxic Exposure: Contact with agents or substances in the interior of the spacecraft or spacesuit that can affect the health and performance of the crewmembers.

Training: The act of undertaking a course of instruction in skills, knowledge or fitness that relate to specific competencies needed for spaceflight missions. Training has specific goals of improving and individual or team’s capability, capacity, and performance.

Ultrasound: An imaging modality to examine the internal organs using very high frequency sound waves.

Workload: Level of demand placed on a crewmember's physical, cognitive, and/or temporal resources in a unit of time.

APPENDIX D

REQUIREMENTS COMPLIANCE MATRIX

D.1 PURPOSE

Due to the complexity and uniqueness of spaceflight, it is unlikely that all of the requirements in a NASA Technical Standard will apply. Table D.2-1—Requirements Compliance Matrix below contains this NASA Technical Standard's technical authority requirements and may be used by programs and projects to indicate requirements that are applicable or not applicable to help minimize costs. Enter "Yes" in the "Applicable" column if the requirement is applicable to the program or project or "No" if the requirement is not applicable to the program or project. The "Comments" column may be used to provide specific instructions on how to apply the requirement or to specify proposed tailoring. The choice of having no applicability must be explained and justified in the Comments section.

D.2 REQUIREMENTS COMPLIANCE MATRIX

Table D.2-1—Requirements Compliance Matrix

NASA-STD-3001, Volume 2					
Section	**Title**	**Number**	**Requirement Text**	**Applicable (Enter Yes or No)**	**Comments**
3.1	Medical Management	[V1 3000]	All terrestrial and in-mission medical aspects included in this NASA Technical Standard shall be in accordance with current U.S. and appropriate partners medical care standards, with limitations as imposed by mission constraints, and managed by the Flight Medicine team, which includes, but is not limited to, the Flight Medicine Clinic, Flight Surgeon, Deputy Flight Surgeon, and their designees, including the in-mission medical care providers (Crew Medical Officers).		
3.2	Selection and Recertification	[V1 3001]	Crewmembers shall be medically and psychologically selected and annually recertified following the guidance in OCHMO-STD-100.1A, NASA Astronaut Medical Standards Selection and Annual Recertification.		

NASA-STD-3001, Volume 2					
Section	**Title**	**Number**	**Requirement Text**	**Applicable (Enter Yes or No)**	**Comments**
3.3	Pre-Mission Preventive Health Care	[V1 3002]	Pre-mission preventive strategies shall be used to reduce in-mission and long-term health medical risks, including, but not limited to: a. Optimization of nutrition. b. Vitamin D supplementation. c. Assessment of medications needed for in-flight use. d. Triennial imaging of bone mineral density. e. Maintenance of optimal aerobic and strength physical fitness. f. Maintenance of flexibility, agility, and balance. g. Annual and preflight physicals/periodic health evaluations. h. Preventive dental care. i. Vaccinations as recommended by CDC and local epidemiological conditions as recommended by flight medicine team (eg. influenza, tetanus toxoid, varicella zoster vaccine, severe acute respiratory syndrome (SARS), coronavirus (Covid-19)), etc. j. Behavioral health and performance training. k. Flight surgeon monitoring of crewmembers during hazardous training and preflight science testing. l. Total radiation dose control/monitoring. m. Pre-mission Health-Stabilization Program (HSP) to reduce the likelihood of contracting an infectious disease before launch. n. Assisted Reproductive Technology (ART) if desired by the crewmember to preserve gametocytes prior to missions with exposure to radiation.		
3.4	In-Mission Preventive Health Care	[V1 3003]	All programs shall provide training, in-mission capabilities, and resources to monitor physiological and psychosocial well-being and enable delivery of in-mission preventive health care, based on epidemiological evidence-based probabilistic risk assessment (PRA), individual crewmember needs, clinical practice guidelines, flight surgeon expertise, historical review, mission parameters, and vehicle-derived limitations. These analyses consider the needs and limitations of each specific vehicle and design reference mission (DRM) with particular attention to parameters such as mission duration, expected return time to Earth, mission route and destination, expected radiation profile, concept of operations, and more. In-mission preventive care includes, but is not limited to:		

NASA-STD-3001, Volume 2					
Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
			a. Periodic monitoring of general health status. b. Optimization and periodic monitoring of nutrition intake – To include caloric density and macro/micronutrients (including antioxidants, flavonoids, lycopene, omega-3 fatty acids, lutein, sterols, and prebiotics), to support multiple physiological systems such as immune function, bone and muscle health, effectiveness of radiation damage repair mechanisms, cognitive and mental well-being, microbiome, etc. Optimization of nutrition intake also includes such aspects as food palatability and food variety, to support psychological well-being and crew morale. c. Vitamin D supplementation – For bone and immune function. d. Maintenance and periodic monitoring of aerobic and strength physical fitness – For maintenance of muscle strength and aerobic capacity (essential for performance of safety-critical physical tasks such as emergency vehicle egress), bone strength, cardiovascular health, immune system performance, sensorimotor function, behavioral health/stress relief, and reduction in renal stone formation. e. Maintenance and periodic monitoring of flexibility, agility, and balance – For sensorimotor function (essential for performance of safety-critical physical tasks such as emergency vehicle egress). f. Maintenance and monitoring of work/rest schedules and optimal sleep/circadian rhythm. g. Maintenance and monitoring of environmental parameters at optimal levels for crew health and performance, as outlined in other technical requirements. h. Prevention of pressure-related illness or injury (dysbarism) by utilizing the appropriate prebreathe and equipment protocols. i. Preventive dental care. j. Hearing conservation and protection (as required in [V2 9057] Hearing Protection Provision), including periodic monitoring. k. Optimization and periodic monitoring of psychosocial countermeasures for team cohesion, privacy, social isolation, and sensory deprivation.		

NASA-STD-3001, Volume 2					
Section	**Title**	**Number**	**Requirement Text**	**Applicable (Enter Yes or No)**	**Comments**
			l. Preventive measures for orthostatic intolerance and neuro-vestibular challenges during G-transitions and adaptation to new gravity environment. m. Spaceflight Associated Neuro-Ocular Syndrome (SANS) periodic monitoring, and prevention with to-be-determined countermeasures (to be validated by research in the coming years). n. Periodic monitoring of vascular motility and patency of venous drainage pathways in the neck as well as the deep veins in the lower extremities. o. Optimization and periodic monitoring of immune function via implementation of a suite of multi-component countermeasures. p. For missions that land on planetary bodies – Training, capabilities, and resources for rehabilitation on the planetary surface, analogous to the functions of the post-Earth-landing recovery team, rehabilitation team, and flight surgeon team to enable surface mission success. q. Monitoring and management of any future risks as they emerge.		
3.5	In-Mission Medical Care	[V1 3004]	All programs shall provide training, in-mission medical capabilities, and resources to diagnose and treat potential medical conditions based on epidemiological evidence-based PRA, individual crewmember needs, clinical practice guidelines, flight surgeon expertise, historical review, mission parameters, and vehicle-derived limitations. These analyses consider the needs and limitations of each specific vehicle and design reference mission (DRM) with particular attention to parameters such as mission duration, expected return time to Earth, mission route and destination, expected radiation profile, concept of operations, and more. . In-mission capabilities (including hardware and software), resources (including consumables), and training to enable in-mission medical care, and behavioral care, are to include, but are not limited to: a. Medical system architecture and infrastructure (i.e., electronic medical records(including data encryption /protection), inventory monitoring/maintenance, medical stowage allocation [including pressurized or refrigerated volume], etc.). b. Medical kits (personal, routine, emergency, and survival) and resources, including appropriate pharmaceuticals, equipment, and supplies selected for ease-of-use, and personal protective equipment		

NASA-STD-3001, Volume 2					
Section	**Title**	**Number**	**Requirement Text**	**Applicable (Enter Yes or No)**	**Comments**
			(e.g., biohazards and sharps containment). c. Configuring environment for medical care (including privacy considerations). d. Obtaining and recording history of medical encounter. e. Performing and recording the physical exam. f. Periodic monitoring and treatment of dental health as appropriate. g. Capability to provide deployed crewmembers with optical correction (e.g., glasses). h. Assessing, recording, monitoring, and trending vital signs and additional physiological and behavioral health signs. i. Conducting ancillary tests as needed, including imaging (e.g., cardiac, vascular, ocular), laboratory analyses, and electrocardiography. j. Performing procedures and recording outcomes. k. Providing physical restraints for the patient, caregiver, and medical equipment appropriate to specific gravity environments of the mission con-ops. l. Recording treatment plan and its execution as appropriate. m. Administering and managing all medications. n. Consumables. o. Capability to diagnose and treat – pressure related illness or injury (dysbarism). p. Monitoring and balancing work/rest schedule. q. Treating neurobehavioral disorders with medical devices and/or evidence-based asynchronous behavioral health treatment protocols available on electronic devices. r. Private two-way communication (e.g. audio, video, messaging, images) with ground medical and psychological support, family, and crew support system. s. Private transmission of medical data (including imaging) to ground medical support or other mission vehicles. t. Means of providing autonomous medical care and advanced life support. u. Medical evacuation. v. Palliative care.		

NASA-STD-3001, Volume 2					
Section	**Title**	**Number**	**Requirement Text**	**Applicable (Enter Yes or No)**	**Comments**
3.6	Medical Evacuation	[V1 3007]	Medical evacuation to a location with a higher level of medical care shall be available for illness/injuries occurring during a spaceflight mission, which are beyond the medical capabilities available at the crew's location.		
3.7	In-Mission Evacuation to Definitive Medical Care Facilities	[V1 3008]	Plans and vehicle(s) shall be available to transport severely ill or injured crewmember(s) to appropriate Medical Care Facilities, including Definitive Medical Care Facilities (DMCF) in the event of a contingency scenario.		
3.8	Palliative Comfort Care	[V1 3009]	The program shall provide in-mission palliative comfort care capabilities for medical scenarios where onboard medical resources have been exhausted, or a timely return to Earth (or another location of higher medical capability) is not feasible, and survival of the crewmember has been determined to be impossible.		
3.9	Termination of Care	[V1 3010]	Each human spaceflight program shall have criteria for termination of care available prior to flight.		
3.10.1	Pre-Mission Crew Mortality Plan	[V1 3050]	The program shall develop and execute a Crew Mortality Plan and determine legal jurisdiction prior to each mission (including preflight activities, launch, operations, and landing).		
3.10.2	Pronouncement of Crew Death	[V1 3051]	The program shall define the process to medically assess the death of an in-mission crewmember and legally record the pronouncement of death.		
3.10.3	In-Mission Forensic Sample Collection	[V1 3052]	The program shall have the capability to obtain in-mission forensic evidence from a deceased crewmember and return this evidence to Earth.		
3.10.4	Crew Mortality Remains Return to Earth	[V1 3053]	The program shall be capable of returning the remains of a deceased crewmember back to Earth.		
3.10.5	In Situ Disposition of Deceased Crewmember Remains	[V1 3054]	The program shall meet planetary protection regulations in the case of in situ or jettison disposition of the remains of a deceased crewmember.		
3.10.6	Surviving Crew Support	[V1 3055]	The program shall provide behavioral health support to the deceased crewmembers family, surviving crewmembers, and support team in-mission and post-mission.		

NASA-STD-3001, Volume 2					
Section	**Title**	**Number**	**Requirement Text**	**Applicable (Enter Yes or No)**	**Comments**
3.10.7	Crew Mortality Mishap Investigation Plan	[V1 3056]	The program shall have plans in place prior to a mission to gather the appropriate data to support a Presidential Commission mishap investigation.		
3.11	Terrestrial Launch/Landing Medical Support	[V1 3012]	All programs shall have medical capability at the site of terrestrial launch and landing to address nominal operations and launch/landing contingencies, including, but not limited to the following: a. HSP technical requirements for the crew, the crew's family, and supporting personnel for purpose of disease prevention. b. Access to the full spectrum of medical capabilities, from routine medical and behavioral health care to advanced trauma life support (ATLS) capabilities, advanced cardiac life support (ACLS), or equivalent. c. Incorporation of civilian and/or Department of Defense (DOD) facilities and Emergency Medical Services (EMS).		
3.12.1	DMCF Medical Care	[V1 3013]	The program shall establish medical care agreements with DMCF(s) for each launch and landing (nominal and contingency)location.		
3.12.2	DMCF Transport	[V1 3014]	The program shall have the capability to transport crewmembers to a DMCF for each launch and landing (nominal and contingency) location.		

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Section	**Title**	**Number**	**Requirement Text**	**Applicable (Enter Yes or No)**	**Comments**
3.13	Certification of Training Plans for Launch/Landing Medical Team	[V1 3015]	The organization responsible for crewmember health shall certify training plans for internal NASA medical support personnel who work launch/landing and concur on training plans for external organizations that have a specific medical support training plan in support of a NASA spaceflight program. Training includes but is not limited to: a. Physiological changes occurring as a result of prolonged launch body posture. b. Spaceflight physiology. c. Injuries resulting from launch and landing contingencies (such as trauma, burns, hypoxia, and hypothermia). d. Hazards of exposure to space vehicle-associated toxic chemicals such as propellant, fuels, oxidizers, thermal control fluids, off-gassed products, and their unique treatments and responses. e. Launch/landing suit, helmet, and equipment configuration and safe removal. f. Vehicle-specific failure modes and resulting injury profiles. g. Environmental considerations specific to nominal and off-nominal recovery conditions.		
3.14	Post-Mission Health Care	[V1 3016]	Post-mission health care shall be provided to minimize occurrence of deconditioning-related illness or injury, including but not limited to: a. Physical examinations by a flight surgeon or designated medical support personnel immediately following landing and periodically thereafter, until crewmember status is stable. b. Clinical laboratory tests including but not limited to imaging. c. Physical reconditioning (see [V1 3017] Post-Mission Reconditioning). d. Treatment as required. e. Scheduled days off and rest periods. f. Circadian rhythm entrainment. g. Nutrition assessment and support. h. Behavioral health support for the crewmember and their families to assist with transition back into work and family life. i. Monitoring by a flight surgeon during post-mission scientific investigations that may pose some risk to a deconditioned crewmember's health.		

NASA-STD-3001, Volume 2					
Section	**Title**	**Number**	**Requirement Text**	**Applicable (Enter Yes or No)**	**Comments**
3.15	Post-Mission Reconditioning	[V1 3017]	All programs shall provide the planning, coordination, and resources for an individualized post-mission reconditioning program, specific to each crewmember, mission type, and mission duration. The post-mission reconditioning starts with crew egress at landing and includes a guided, phased reconditioning protocol. The goals of the reconditioning program include the following: a. To ensure the health and safety of returning crew. b. To actively assist the crew's return to full functional abilities and return-to-flight status. c. To actively assist in the crew's return to pre-mission fitness.		
3.16	Post-Mission Long-Term Monitoring	[V1 3018]	Crewmembers returning from spaceflight shall be monitored longitudinally for health, behavioral health, and well-being parameters in a standardized manner.		
4.1.1	Microgravity EVA Aerobic Capacity	[V1 4001]	Crewmembers shall maintain an in-mission VO2max at or above 32.9 ml/(min/kg) for missions with microgravity EVAs as determined by either direct or indirect measures.		
4.1.2	Extraterrestrial Surface EVA Aerobic Capacity	[V1 4002]	Crewmembers shall maintain an in-mission maximum aerobic capacity (VO2max) at or above 36.5 ml/(min/kg) for missions with celestial extraterrestrial surface EVAs as determined by either direct or indirect measures.		
4.1.3	In-Mission Aerobic Capacity	[V1 4003]	The in-mission aerobic capacity shall be maintained, either through countermeasures or work performance, at or above 80% of the pre-mission capacity determined by either direct or indirect measures.		
4.1.4	Post-Mission Aerobic Capacity	[V1 4004]	The post-mission reconditioning shall be aimed at achieving a VO2max at or above the crewmember's pre-mission values.		
4.2.1	Pre-Mission Sensorimotor	[V1 4005]	Pre-mission sensorimotor functioning shall be within normal clinical values for age and sex of the crewmember population.		
4.2.2	In-Mission Fitness for Duty Sensorimotor	[V1 4006]	In-mission Fitness-for-Duty technical requirements shall be guided by the nature of mission-associated critical operations (such as, but not limited to, vehicle control, robotic operations, EVAs).		
4.2.3	In-Mission Fitness for Duty Sensorimotor Metrics	[V1 4007]	In-mission Fitness-for-Duty technical requirements shall be assessed using metrics that are task specific.		
4.2.4	Sensorimotor Performance Limits	[V1 4008]	Sensorimotor performance limits for each metric shall be operationally defined.		

NASA-STD-3001, Volume 2					
Section	**Title**	**Number**	**Requirement Text**	**Applicable (Enter Yes or No)**	**Comments**
4.2.5	Sensorimotor Countermeasures	[V1 4009]	Countermeasures shall maintain sensorimotor function within performance limits.		
4.2.6	Post-Mission Sensorimotor Reconditioning	[V1 4010]	Post-mission reconditioning shall be monitored and aimed at returning to baseline sensorimotor function.		
4.3.1	Mission Cognitive Status	[V1 4011]	Pre-mission, in-mission, and post-mission crew behavioral health and crewmember cognitive status shall be within clinically accepted values as judged by behavioral health evaluation.		
4.3.2	End of Mission Cognitive Assessment and Treatment	[V1 4012]	End-of-mission assessment and treatment for crewmember cognitive status shall include cognitive assessment, monitoring, and as needed, transitioning the crewmember back to pre-mission values.		
4.3.3	End of Mission Psychosocial Assessment	[V1 4013]	End-of-mission assessment and treatment for behavioral health of the crewmember shall include behavioral health and psychosocial assessment, monitoring, and as needed, transitioning the crewmember back into terrestrial work, family, and society.		
4.3.4	Completion of Critical Tasks	[V1 4014]	The planned number of hours for in-mission completion of critical tasks and events, workday, physical activity/exercise, and planned sleep period shall have established limits to assure continued crew health and safety.		
4.4.1	Pre-Mission Hematological/Immunological Function	[V1 4015]	Crewmember pre-launch hematological/immunological function shall be within normative ranges established for the healthy general population.		
4.4.2	In-Mission Hematological/Immunological Countermeasures	[V1 4016]	In-mission countermeasures shall be in place to sustain hematological/immunological parameters within the normal range as determined by direct or indirect means.		
4.4.3	Hematology and Immunology Countermeasures and Monitoring	[V1 4017]	Countermeasures and monitoring shall ensure immune and hematology values remain outside the critical values, i.e., the level that represents a significant failure of the hematological/immunological system, and is associated with specific clinical morbidity, defined for specific parameters.		
4.4.4	Post-Mission Hematological/Immunological	[V1 4018]	Post-mission assessment and treatment shall be aimed at returning to pre-mission hematological/immunological baseline.		
4.5.1	Pre-Mission Nutritional Status	[V1 4019]	Pre-mission nutritional status shall be assessed, and any deficiencies mitigated prior to launch.		

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Section	**Title**	**Number**	**Requirement Text**	**Applicable (Enter Yes or No)**	**Comments**
4.5.2	In-Mission Nutrient Intake	[V1 4020]	Programs shall provide each crewmember with 100% of their calculated nutrient and energy requirements, based on an individual's age, sex, body mass (kg), height (m), and an appropriate activity factor.		
4.5.4	Post-Mission Nutritional Assessment and Treatment	V1 4022]	Post-mission nutritional assessment and treatment shall be aimed at returning to pre-mission baseline.		
4.6.1	Pre-Mission Muscle Strength and Function	[V1 4023]	Pre-mission muscle strength and function shall meet or exceed the values in Table 4.6-1—Pre-Mission Muscle Strength Technical Requirements.		
4.6.2	In-Mission Skeletal Muscle Strength	[V1 4024]	Countermeasures shall maintain in-mission skeletal muscle strength at or above 80% of baseline values.		
4.6.3	Post-Mission Muscle Reconditioning	[V1 4025]	Post-mission reconditioning shall be aimed at returning to baseline muscle strength.		
4.7.1	Pre-Mission Bone Mineral Density	[V1 4026]	Crewmembers' pre-mission bone mineral density (BMD) T-scores for total hip and lumbar spine (L1-L4), as measured by mass dual energy X-ray absorptiometry (DXA) shall be consistent with an age, sex, gender, and ethnic-matched population.		
4.7.2	In-Mission Bone Countermeasures	[V1 4027]	Countermeasures shall maintain bone mineral density of the hip and spine at or above 95% of pre-mission values and at or above 90% for the femoral neck.		
4.7.3	Post-Mission Bone Reconditioning	[V1 4028]	Post-mission reconditioning shall be aimed at returning bone mineral density to pre-mission baseline.		
4.8.1	As Low as Reasonably Achievable (ALARA) Principle	[V1 4029]	All crewmember radiation exposures shall be minimized using the ALARA principle.		
4.8.2	Career Space Permissible Exposure Limit for Space Flight Radiation	[V1 4030]	An individual crewmember's total career effective radiation dose due to spaceflight radiation exposure shall be less than 600 mSv. This limit is universal for all ages and sexes.		
4.8.3	Short-Term Radiation Limits – Solar Particle Events	[V1 4031]	The program shall protect crewmembers from exposure to the design reference solar particle event (SPE) environment proton energy spectrum (sum of the October 1989 events) to less than an effective dose of 250 mSv.		

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Section	**Title**	**Number**	**Requirement Text**	**Applicable (Enter Yes or No)**	**Comments**
4.8.4	Crew Radiation Limits for Nuclear Technologies	[V1 4032]	Radiological exposure from nuclear technologies emitting ionizing radiation to crewmembers (e.g., radioisotope power systems, fission reactors, etc.) shall be less than an effective dose of 20 mSv per mission year (prorated/extrapolated to mission durations) and utilizing the ALARA principle.		
4.8.5	Crew Radiation Limits from Galactic Cosmic Radiation	[V1 4033]	For habitable space systems designed to support crew for > 60 days, the program shall protect crewmembers from exposure to the galactic cosmic ray (GCR) environment to less than a NASA effective dose (as defined in NASA-STD-3001, Volume 1 [V1 4030] Career Space Permissible Exposure Limits for Spaceflight Radiation) rate of 1.3 mSv/day for systems in free space and to less than 0.9 mSv/day for systems on planetary surfaces.		
5.1	Medical Training	[V1 5001]	Medical training shall be provided to crewmembers, flight surgeons (FSs), mission control support staff, and other ground support personnel (GSP).		
5.2	Crewmember Training	[V1 5002]	Beginning with the crewmember candidate year, general medical training, including but not limited to, first aid, cardiopulmonary resuscitation (CPR), altitude physiological training, carbon dioxide exposure training, familiarization with medical issues, procedures of spaceflight, psychological training, toxicology, medical equipment, and supervised physical conditioning training shall be provided to the astronaut corps.		
5.2.1	Crew Medical Officer Medical Training	[V1 5003]	Crewmembers who have received a mission assignment as a Crew Medical Officer (CMO) shall be provided with detailed and specific medical training, including but not limited to, health issues, space physiology, behavioral health, medical procedures, medical equipment, toxicology, and countermeasures.		
5.2.1.1	Crew Medical Officers Quantity	[V1 3006]	The program(s) shall train a minimum of two crewmembers per vehicle/platform as Crew Medical Officers (CMOs).		
5.2.2	Medical Training Verification	[V1 5004]	Medical Training shall be verified for all personnel.		
5.3	Flight Surgeon Training	[V1 5005]	Flight Surgeons, including but not limited to NASA and international partners, assigned to support the subject space program shall receive training and certification in accordance with a program-specific training plan.		

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Section	**Title**	**Number**	**Requirement Text**	**Applicable (Enter Yes or No)**	**Comments**
5.4	Medical Operations Flight Controller Training	[V1 5006]	All Medical Operations personnel staffing the Mission Control Center (MCC) shall be trained and certified according to program-specific training and certification plans.		
5.5	Support Personnel Training	[V1 5007]	Supervised training programs shall be implemented for individuals including but not limited to NASA personnel, international partners, and commercial/private space programs, who require knowledge of space medicine or flight medical procedures, such as flight directors, medical consultants, and/or other personnel deemed appropriate as part of the Medical and Crew Health Technical Requirements Document.		
5.6	Psychological Mission Training	[V1 5008]	Specific pre-mission briefings and training shall be provided as appropriate to the commander (CDR), CMOs, crewmembers, key ground personnel, and crew families concerning the significant psychological and social phenomena that may arise in all phases of a mission.		
5.7	Physiological Exposure Mission Training	[V1 5009]	Physiological training shall be provided to assist crewmembers with pre-mission familiarization to in-flight exposures including but not limited to: carbon dioxide [CO2] exposure training, hypoxia training/instruction, centrifuge, and high-performance aircraft microgravity adaptation training in preparation for each mission.		
6.1	Circadian Shifting Operations and Fatigue Management	[V1 6001]	Crew schedule planning and operations shall be provided to include circadian entrainment, work/rest schedule assessment, task loading assessment, countermeasures, and special activities.		
6.2.1	Private Medical Communication Schedule	[V1 6002]	Private medical communications shall be scheduled on a routine basis, as determined by the Flight Surgeon, at a frequency dictated for short- or long-duration missions		
6.2.2	Private Medical Communications Information Delivery	[V1 6003]	Private Medical Communications information that is sent to/from the ground via spacecraft communication systems shall be considered private communication.		
6.3.1	Behavioral Health and Performance Provisions	[V1 6004]	Program shall implement psychological/behavioral health support programs for the crewmembers, key ground personnel, and crewmember families throughout the mission.		
6.3.2.1	Psychological Communication Schedule	[V1 6010]	A PPC shall be scheduled on a routine basis, as determined by the Behavioral Health Provider, at a frequency dictated for short- or long-duration missions		

NASA-STD-3001, Volume 2					
Section	**Title**	**Number**	**Requirement Text**	**Applicable (Enter Yes or No)**	**Comments**
6.3.2.2	Psychological Communications Information Delivery	[V1 6011]	Psychological information that is sent to/from the ground via spacecraft communication systems shall be considered private communication.		
6.4	Extravehicular Activities (EVAs)	[V1 6006]	All crewmembers shall be medically cleared to perform an EVA by ground medical support personnel prior to each EVA.		
6.5.1	Crew Health Operations Concept Document	[V1 6008]	The program(s) shall develop a crew health concept of operations document to define the medical and health care concepts during all phases of the spaceflight program.		
6.5.2	Medical and Crew Health Technical Requirements Document	[V1 6009]	The program(s) shall develop a medical and crew health technical requirements document based on the concepts outlined in the program-specific crew health operations concept (CHOC) document and NASA-STD-3001.		
7.1	Crew Health Results	[V1 7001]	The results of all crew health monitoring shall be kept in a permanent retrievable format for evaluation including trend analysis.		
7.2	Crew Records Communication	[V1 7002]	The method of transmission of crewmembers' medical health data shall meet the medical operational needs of the program.		
7.3	Crew Records Security	[V1 7002]	The method for handling, storing, and transmission of crewmembers' medical health records shall be secured.		

APPENDIX E

HEALTH AND MEDICAL CARE TECHNICAL REQUIREMENTS

EPIDEMIOLOGICAL EVIDENCE-BASED PROBABILISTIC RISK ASSESSMENT (PRA)

E.1 PURPOSE

This Appendix provides information relative to health and medical care probabilistic risk assessment.

E.2 EPIDEMIOLOGICAL EVIDENCE-BASED PROBABILISTIC RISK ASSESSMENT (PRA)

E.2.1 Background

The Health and Medical Care Technical Requirements reference an epidemiological evidence-based PRA as a decision support tool to aid clinical stakeholders, engineering teams, and medical mission planners in the development of medical capabilities to treat the most likely medical conditions that may occur for a specific mission. The purpose of this Appendix is to provide background on this PRA and provide an outline of steps to consider during the process.

Epidemiological evidence-based medical PRA is a comprehensive, structured, and logical analysis method aimed at providing probability of occurrence of medical conditions based on past spaceflight experience coupled with terrestrial occurrences of medical conditions. Presently, The Integrated Medical Model (IMM) that was developed by the Human Research Program is a stochastic decision support tool that is available for use by clinical stakeholders, spaceflight mission planners, and medical system designers in assessing risks and optimizing medical systems. Other approved PRA decision support tools may also be utilized to meet the intent of the health and medical care technical requirements. Refer to section 3 for Health and Medical Technical Requirements description.

E.2.2 Integrated Medical Model (IMM) Overview

The IMM incorporates "best evidence" with data from past missions, computer models, and comparable populations on Earth, to provide a quantifiable assessment of medical risk for a given mission scenario. The IMM also identifies medical resources, such as equipment and supplies, which are necessary for treating the medical conditions most likely to occur during the mission. Using the Monte Carlo simulation technique (a random sampling of the data inputs as described by their statistical distribution), the IMM can forecast medical outcomes, helping to provide more appropriate medical support for flight crews. The medical conditions addressed by the IMM range from minor conditions (such as headaches and nasal congestion) to more serious conditions (such as sudden cardiac arrest and kidney failure).

The IMM currently derives estimates of fire/smoke/toxic inhalation risks from the ISS PRA fire model. IMM uses incidence data generated by independent predictive health models and by Bayesian analysis. The incidence of these events can be used as estimates for other vehicles, if appropriate, or updated data can be provided for the specific vehicle.

The IMM requires the user to provide the mission duration, location, number of EVAs and crew attributes (for example quantity or sex) and will generate the type and probability of occurrence (likelihood) of medical events. IMM also assumes that the crew selection and Health Stabilization Program technical requirements are followed to ensure that the crew is in the best health posture prior to the mission. Refer to Table E.2-1—Sample IMM Output.

Table E.2-1—Sample IMM Output

	Medical Condition	Likelihood
1	Late Insomnia	13.85 per mission
2	Skin Abrasion	9.86 per mission
3	Skin Rash	9.83 per mission
4	Eye Abrasion	7.42 per mission
5	Late Headache	5.25 per mission
6	Space Motion Sickness (SAS)	4.37 per mission
7	Diarrhea	3.53 per mission
8	Nasal Congestion	3.51 per mission
9	Respiratory Infection	3.46 per mission
10	Back Injury	3.41 per mission
11	Barotrauma (Ear/Sinus Block)	3.28 per mission
12	Back Pain (SAS)	3.15 per mission
13	Insomnia (SAS)	2.70 per mission
14	Shoulder Sprain/Strain	2.43 per mission
15	CO_2 Headache	2.15 per mission
16	Headache (SAS)	2.11 per mission
17	Spaceflight Associated Neuro-ocular Syndrome (SANS)	2.08 per mission
18	Urinary Tract Infection	1.44 per mission
19	Skin Infection	1.38 per mission
20	Elbow Sprain/Strain	1.32 per mission
21	Ankle Sprain/Strain	1.22 per mission
22	Allergic Reaction	1.18 per mission
23	Pharyngitis	1.17 per mission
24	Constipation	1.02 per mission
25	Neck Injury	0.99 per mission
26	Mouth Ulcer	0.96 per mission
27	Dental Caries	0.88 per mission
28	Knee Sprain/Strain	0.78 per mission
29	Paresthesia [Extravehicular Activity (EVA)]	0.65 per mission
30	Indigestion	0.64 per mission
31	Eye Chemical Burn	0.64 per mission
32	Sinusitis	0.64 per mission
33	Hearing Loss	0.57 per mission
34	Wrist Sprain/Strain	0.55 per mission
35	Eye Infection	0.53 per mission
36	Hip Sprain/Strain	0.45 per mission

	Medical Condition	Likelihood
37	Gastroenteritis	0.42 per mission
38	Fingernail Delamination [Extravehicular Activity (EVA)]	0.40 per mission
39	Otitis Externa	0.32 per mission
40	Otitis Media	0.30 per mission
41	Hemorrhoids	0.22 per mission
42	Lower Extremity Stress Fracture	0.13 per mission
43	Urinary Retention	0.11 per mission
44	Skin Laceration	0.11 per mission
45	Influenza	0.11 per mission
46	Finger Dislocation	0.11 per mission
47	Shingles	0.11 per mission
48	Dental Abscess	0.068 per mission
Table E.2-2—Medical Conditions Considered of High Likelihood or High Consequence for Spaceflight Missions summarizes the most common conditions that need to be assessed for missions up to 6 months. The items in bold and with an asterisk are the most common and should be considered for any mission duration.		

Table E.2-2—Medical Conditions Considered of High Likelihood or High Consequence for Spaceflight Missions

Category	Specific Condition
Environmental or spaceflight-induced medical conditions	Acute radiation syndrome **Allergic reaction *** Altitude sickness **Anaphylaxis *** **Back pain (space-adaptation related) *** Barotrauma (ear/sinus block) Burn (thermal) Burns secondary to fire Celestial dust exposure Choking/obstructed airway Cold injury (chilblains frostbite) **Constipation (space-adaptation related) *** Decompression sickness Embolism Electrical injury Epistaxis (nosebleed, space adaptation related) EVA-related dehydration **Headache (CO_2 related) *** **Headache (space-adaptation related) *** Hearing loss (noise related) Heat illness Hypothermia Medication adverse reaction **Nasal congestion (space-adaptation related) *** Nutritional deficiency **Space motion sickness (space-adaptation related) *** Smoke/combustion product inhalation Toxic inhalation injury **Urinary incontinence (space-adaptation related) *** **Urinary retention (space-adaptation related) ***

Category	Specific Condition
Ophthalmic conditions	Acute glaucoma **Chemical eye injury *** **Corneal abrasion *** Corneal ulcer **Eye foreign body *** Eye infection Eyelid/anterior eye infection Loss of vision Penetrating eye injury Retinal detachment/injury SANS
Ear, nose, and throat conditions	Acute sinusitis Cerumen impaction Epistaxis (nosebleed) Hearing loss Otitis externa Otitis media Pharyngitis Respiratory infection
Dental/oral conditions	Caries Crown loss Dental abscess Filling loss Fractured tooth/Exposed pulp Oral ulcer Tooth loss (avulsion/luxation)
Cardiovascular conditions	Acute coronary syndrome Angina/Myocardial infarction Cardiac dysrhythmias (atrial fibrillation/flutter) Cardiogenic shock **Gravity transition orthostatic intolerance *** Hypertension Sudden cardiac arrest Traumatic hypovolemic shock Venous thromboembolism
Pulmonary and other chest conditions	Chest injury – Blunt Chest injury – Penetrating Reactive airway/asthma Respiratory tract infection (lower) Respiratory tract infection (upper)
Gastrointestinal and other abdominal conditions	Abdominal injury – Blunt Abdominal injury – Penetrating Abdominal wall hernia Acute cholecystitis / Biliary colic Acute diverticulitis Acute pancreatitis Appendicitis **Constipation *** **Diarrhea *** Gastroenteritis Hemorrhoids **Indigestion *** Reflux/esophagitis Small bowel obstruction

Category	Specific Condition
Genitourinary conditions	Abnormal uterine bleeding Acute kidney injury Acute prostatitis Bacterial vaginosis Nephrolithiasis **Urinary tract infection *** Unprotected intercourse **Vaginal yeast infection ***
Musculoskeletal conditions	Acute arthritis Acute compartment syndrome Back injury (sprain/strain) Dislocation (finger, elbow, shoulder) Fingernail delamination (EVA related) Fracture (finger, hand, wrist/arm, distal leg, hip/proximal femur, thoracolumbar spine, cervical spine) Hand injury (EVA related) Joint sprain/strain (shoulder, elbow, wrist, hip, knee, ankle) Lower extremity stress fracture Muscular sprain/strain Neck injury (sprain/strain) Overuse injury – Upper or lower extremity Paresthesia Subungual hematoma Suit contact injury (EVA related) Vertebral disc injury
Dermatological conditions	Burn – Chemical, skin **Cellulitis – Bacterial skin infection *** Herpes zoster (Shingles) **Skin abrasion *** **Skin laceration *** **Skin rash *** Toxic dermal exposure Viral/fungal skin infection
Neurologic conditions	Benzodiazepine/Opiate overdose Cerebrovascular accident **Gravity transition neurovestibular disturbance *** **Headache *** Head trauma (major) Head trauma (minor) Neurogenic shock Neuropathy (Central – impingement) Paresthesia Seizure

Category	Specific Condition
Psychological, cognitive, or behavioral conditions	**Acute stress *** **Adjustment reaction *** **Anxiety/panic *** Apathy/low motivation **Cognitive disturbance *** Delirium Depression Grief reaction **Insomnia/sleep disturbances/circadian misalignment *** **Interpersonal conflict (i.e., team, ground, family) *** Lack of meaningful work and/or monotony **Mood disturbance (e.g., irritability) *** Neurocognitive disorders (adjustment, mood, anxiety, trauma-related, or stress-related) Psychosis Relationship problems (family, crew, mission support personnel) Work overload/burnout/exhaustion
Other conditions not captured elsewhere	Anemia/Iron deficiency Sepsis
Conditions noted with an asterisk (*) should be addressed on every mission regardless of the DRM parameters.	

E.2.3 Medical System Development using PRA Integrated Medical Model (IMM) Data

The IMM output of probability of occurrence of medical conditions that may occur in-mission is a quantitative starting point for stakeholders to consider while developing an in-mission medical system. One limitation is that IMM was developed for application to ISS missions, but it may be applied to other design reference missions if the appropriate limitations are considered during interpretation of results. Figure E.2-1—Outline for the Use of PRA Data to Aid in the Generation of a Medical Conditions List, outlines the steps to utilize the PRA/IMM data in the development of a health and medical care system.

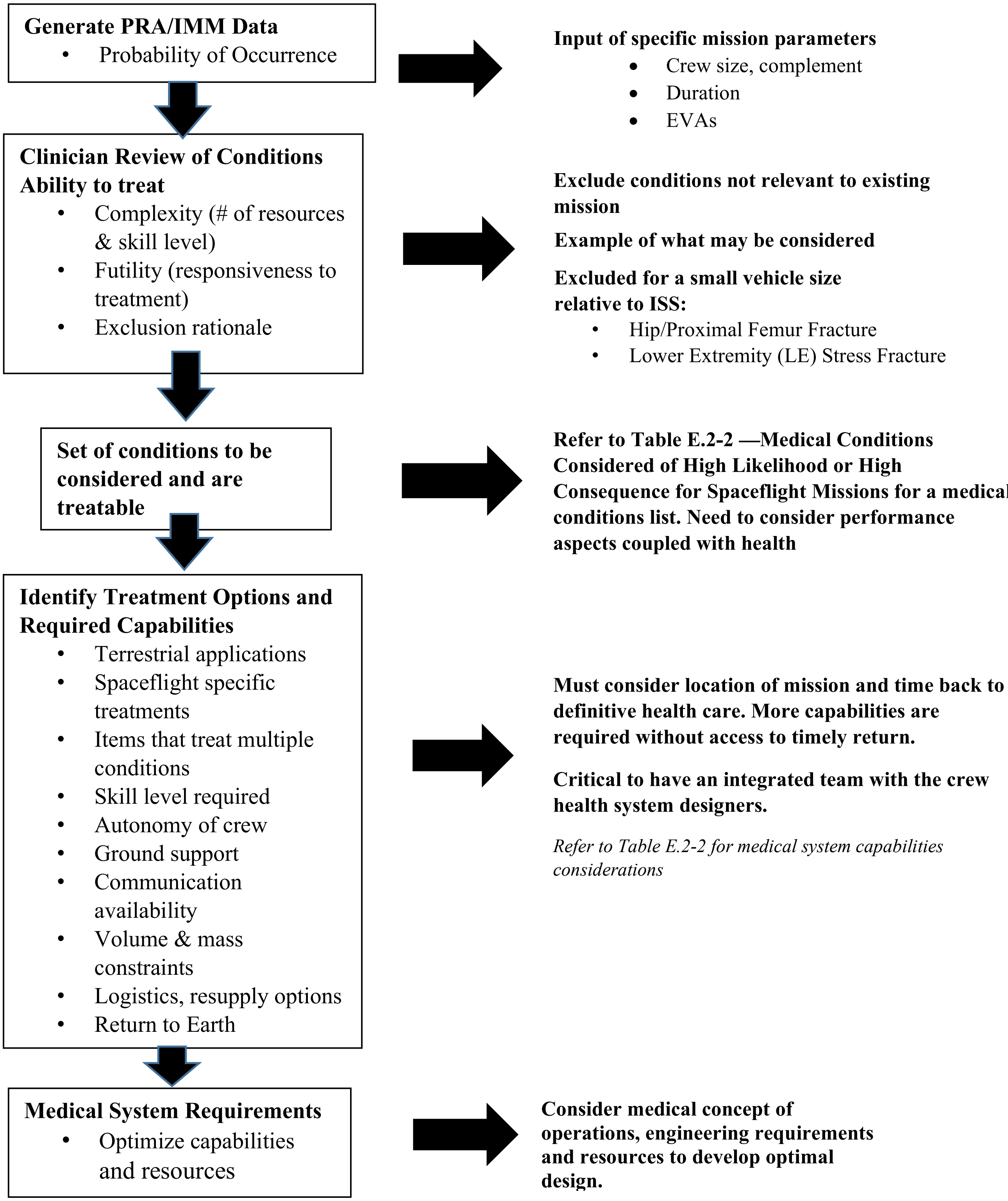

Figure E.2-1— Notional Sample Outline for the use of PRA data to aid in the generation of a medical conditions list