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FOREWORD

This Standard is published by the National Aeronautics and Space Administration (NASA) to provide uniform engineering and technical requirements for processes, procedures, practices, and methods that have been endorsed as standard for NASA programs and projects, including requirements for selection, application, and design criteria of an item.

This Standard is approved for use by NASA Headquarters and NASA Centers, including Component Facilities and Technical and Service Support Centers.

This Standard establishes requirements for providing a healthy and safe environment for crewmembers and for providing health and medical programs for crewmembers during all phases of space flight. Requirements are established to optimize crew health and performance, thus contributing to overall mission success, and to prevent negative long-term health consequences related to space flight.

In this document, the Office of the Chief Health and Medical Officer establishes NASA's space flight crew health requirements for the pre-flight, in-flight, and post-flight phases of human space flight. These requirements apply to all NASA human space flight programs and are not developed for any specific program. However, while some of the existing programs, such as the International Space Station program, meet the intent and purpose of these requirements currently, these requirements may have implications for longer duration missions and missions with architectures and objectives outside of low Earth orbit. Although the requirements are applicable to the in-flight phase of all space missions, it is anticipated that they will be most relevant during long-duration lunar outpost and Mars exploration missions, since the combined ill effects of exposure to the space environment will be of most concern in those mission scenarios. Requests for information, corrections, or additions to this Standard should be submitted via "Feedback" in the NASA Standards and Technical Assistance Resource Tool at <http://standards.nasa.gov>.

Original signed by:

7/30/2014

Richard S. Williams, M.D.
NASA Chief Health and Medical Officer
NASA Headquarters

Approval Date

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NASA SPACE FLIGHT HUMAN SYSTEM STANDARD

Volume 1: Crew Health

1. SCOPE

1.1 Purpose

The National Aeronautics and Space Administration (NASA) policy for establishing requirements to protect the health and safety of crew and for providing health and medical programs for crewmembers during all phases of space flight, 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 requirements for providing a healthy and safe environment for crewmembers and to provide health and medical programs for crewmembers during all phases of space flight. Standards are established to optimize crew health and performance, thus contributing to overall mission success, and to prevent negative long-term health consequences related to space flight. In this Standard, the Office of the Chief Health and Medical Officer (OCHMO) establishes NASA's space flight crew health requirements for the pre-flight, in-flight, and post-flight phases of human space flight.

Human-system standards are established to guide and focus the development of the crew health requirements as a means of protecting space-faring crews. The requirements presented in this Standard are intended to complement the overall set of human standards for space flight, which also includes NASA-STD-3001, Volume 2: Human Factors, Habitability and Environmental Health; OCHMO 80771201MED NASA Medical Standard for Crewmembers; and current medical standards of clinical practice. Combined, these standards 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 space flight. The requirements described in this document include levels of care, permissible exposure limits, fitness-for-duty criteria, and permissible outcome limits as a means of defining successful operating criteria for the human system. These requirements help ensure mission completion, limit morbidity, and reduce the risk of mortality during space flight missions. Appendix A in this Standard presents an overview document map.

All requirements are based on the best available scientific and clinical evidence, as well as operational experience from Apollo, Skylab, Shuttle, Shuttle/Mir (Russian Space Station), and International Space Station (ISS) missions. 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.

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A Crew Health Concept of Operations document is developed by the Space and Clinical Operations Division at the Johnson Space Center (JSC) for each space flight program and coordinated with the appropriate Program Manager for concurrence. Appendix B in this Standard presents an example Crew Health Concept of Operations outline.

Following the development of the Crew Health Concept of Operations, a Medical Operations Requirements Document (MORD) is developed by the JSC Space and Clinical Operations Division for each program. The MORD details the medical requirements for the program and is consistent with the overall medical concept outlined in the Crew Health Concept document. Appendix C in this Standard presents an example outline of a MORD.

1.2 Applicability

This Standard applies to all NASA human space flight programs and is not developed for any specific program. However, while some of the existing programs, such as the ISS Program, currently meet the intent and purpose of this Standard, these requirements may have implications for longer duration missions and missions with architectures and objectives outside of low Earth orbit (LEO). Although the requirements are applicable to the in-flight phase of all space missions, it is anticipated that they are most relevant during long-duration lunar outpost and Mars exploration missions, since the combined ill effects of exposure to the space environment is of most concern in those mission scenarios. 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.
- d. Supersede any conflicting crew health requirements imposed by other NASA standards.

This Standard is approved for use by NASA Headquarters and NASA Centers, including Component Facilities and Technical and Service Support Centers, and may be cited in contract, program, and other Agency documents as a technical requirement. This Standard may also apply to the Jet Propulsion Laboratory or to other contractors, grant recipients, or parties to agreements only to the extent specified or referenced in their contracts, grants, or agreements.

Requirements are numbered and indicated by the word “shall.” Explanatory or guidance text is indicated in italics beginning in section 4.

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1.3 Tailoring

Tailoring of this Standard for application to a specific program or project shall be formally documented as part of program or project requirements and approved by the NASA Chief Health and Medical Officer.

1.4 Overview

This Standard 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.

This Standard covers the main physiologic parameters associated with the health and successful operation of the human system. It is not all encompassing but does address those areas where the human system has shown particular vulnerability in response to adaptation or exposure to microgravity. The standards set forth in this volume serve as the basis for development of program-specific requirements for maintaining the human system within acceptable operating parameters. To achieve this aim, the requirements of the human system should be considered in vehicle design, mission architecture, countermeasures, and future directed research. Many of the requirements are not in their mature forms and are not fully identified for all areas, perhaps because of a lack of knowledge as to the human system physiology for that length and scale of mission or other reasons. In such cases, top-level functional requirements for these are cited, and further work is/may be required to define the requirement more accurately.

A cascading effect is often seen with system failures in engineering; so it is with the human system as well.

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2. APPLICABLE DOCUMENTS

2.1 General

The documents listed in this section contain provisions that constitute requirements of this standard as cited in the text.

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

2.1.2 Non-use of specific versions as designated shall be approved by the NASA Chief Health and Medical Officer.

The applicable documents are accessible via the NASA Standards and Technical Assistance Resource Tool at <http://standards.nasa.gov> or may be obtained directly from the Standards Developing Organizations or other document distributors.

2.2 Government Documents

NASA

| | |
|-------------------------|---|
| JSC-26546 | NASA International Space Station Flight Surgeon Training and Certification Plan |
| JSC-27384 | Behavioral Health and Performance Program Plan Definition and Implementation Guide |
| NASA-STD-3001, Volume 2 | NASA Space Flight Human System Standard, Volume 2: Human Factors, Habitability, and Environmental Health |
| OCHMO 80771201MED | NASA Crewmembers Medical Standards Volume 1 – Selection and Periodic Certification |
| SSP 50667 Volume A | Medical Evaluation Documents (MED) Volume A – Medical Standards for ISS Crewmembers |
| SSP 50667 Volume B | Medical Evaluation Documents (MED) Volume B – Preflight, In-flight, and Post-flight Medical Evaluation Requirements for Long-Duration ISS Crewmembers |
| SSP 50667 Volume C | Medical Evaluation Documents (MED) Volume C – Medical Standards and Certification Procedures for Space Flight Participants |

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2.3 Non-Government Documents

None.

2.4 Order of Precedence

This Standard establishes requirements to protect the health and safety of crew and to provide health and medical programs for crewmembers during all phases of space flight but does not supersede nor waive established Agency requirements found in other documentation.

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3. ACRONYMS AND DEFINITIONS

3.1 Acronyms and Abbreviations

| | |
|-----------|--|
| ACLS/ATLS | advanced cardiac life support/advanced trauma life support |
| ACSM | American College of Sports Medicine |
| AED | automated external defibrillator |
| ALARA | as low as reasonably achievable |
| AMB | Aerospace Medicine Board |
| ART | assisted reproductive technology |
| BFO | blood forming organ(s) |
| BHP | behavioral health and performance |
| BMD | bone mineral density |
| BPMIF | bench press maximal isometric force |
| BPP | bench press power |
| BPW | bench press work |
| BW | body weight |
| CDR | commander |
| CMO | crew medical officer |
| CNS | central nervous system |
| CPR | cardiopulmonary resuscitation |
| CS | crew surgeon |
| DCS | decompression sickness |
| DMCF | definitive medical care facility |
| DSS | destination service segment |
| DXA | dual energy x-ray absorptiometry |
| EMS | emergency medical services |
| EVA | extravehicular activity |
| FAR | Federal Acquisition Regulation |
| FCOD | Flight Crew Operations Directorate |
| FFD | fitness for duty |
| FMC | flight medicine clinic |
| FS | flight surgeon |
| g | gravity |
| GCR | galactic cosmic rays |
| GSP | ground support personnel |
| HQ | headquarters |
| HSP | health stabilization program |
| IKKE | isokinetic knee extension |
| ISS | International Space Station |
| JSC | Johnson Space Center |
| KE | knee extension |
| KEMIF | knee extension maximal isometric force |
| kg | kilogram(s) |

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| | |
|-----------------|--|
| LEO | low Earth orbit |
| LMS | Life and Microgravity Spacelab |
| LP | leg press |
| LPMIF | leg press maximal isometric force |
| LPP | leg press power |
| LPW | leg press work |
| m | meter(s) |
| max (subscript) | maximum |
| MCC | Mission Control Center |
| MED | medical evaluation documents |
| min | minute(s) |
| ml | milliliter(s) |
| MOD | Mission Operations Directorate |
| MORD | Medical Operations Requirements Document |
| MOSIP | Medical Operations Support Implementation Plan |
| MPB | Medical Policy Board |
| MPCV | Multi-Purpose Crew Vehicle |
| NASA | National Aeronautics and Space Administration |
| NCRP | National Council on Radiation Protection |
| NPD | NASA Policy Directive |
| NPR | NASA Procedural Requirement |
| OCHMO | Office of the Chief Health and Medical Officer |
| Ops | operations |
| OSHA | Occupational Safety and Health Administration |
| PAWS | performance assessment workstation |
| PB | prebreathe |
| PCBA | portable clinical blood analyzer |
| PEL | permissible exposure limit |
| PFC | private family conference |
| PMC | private medical communication/conference |
| POL | permissible outcome limits |
| PPC | private psychological conference |
| PPE | personal protective equipment |
| PRD | Program Requirements Document |
| PSI | pounds per square inch |
| RBE | relative biological effectiveness |
| REID | risk of exposure-induced death |
| SD | standard deviation |
| SMS | space motion sickness |
| SPE | solar particle event |
| SPEL | space permissible exposure limits |
| SSP | Space Station Program |
| STD | standard |
| TV | television |

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| | |
|---------|---|
| U.S./US | United States |
| VGE | venous gas emboli |
| VO | volume of oxygen |
| WHO | World Health Organization |
| WinSCAT | Spaceflight Cognitive Assessment Tool for Windows |

3.2 Definitions

T-score indicates how BMD compares to that of a healthy 30 year-old. Peak bone density is reached by age 30 and should ideally be maintained at this level throughout life. As BMD decreases from this peak density, fracture risk increases. 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. This is the most important value and the one that is used to interpret what BMD means.

Gray (symbol: Gy) is a derived unit of ionizing radiation dose in the International System of Units (SI). It is a measure of the absorbed dose and is defined as the absorption of one joule of radiation energy by one kilogram of matter. (The International System of Units (SI)". Bureau International des Poids et Mesures (BIPM). Retrieved 2010-01-31.)

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4. REQUIREMENTS

4.1 Levels of Medical Care

Medicine typically uses two phrases to discuss care: the level of care that one can provide and the standards of care. These are not interchangeable terms. The term level of care refers to the amount and type of care rendered based on perceived need and the ability of the provider; standard of care is the benchmark and current clinical practice by which that care is provided. Appendix D in this Standard contains additional rationale on levels of care.

The Level of Care that can be provided during any particular space mission is dependent on several factors:

- a. The level of training of the medical provider.*
- b. The technology and advances in medicine that allow such care to be rendered in austere environments.*
- c. The time from the platform to more definitive care.*
- d. The duration of the mission.*
- e. The health and performance of the crew upon embarking on the mission.*
- f. The type of mission, including vehicle, mass, length of stay, extravehicular activities (EVAs), and mission objectives.*
- g. Mission/programmatic philosophy of accepted medical risk (Crew Health Concept of Operations and MORD).*
- h. Medical risk of illness or injury.*
- i. Terrestrial medical standards.*

In addition to human space flight, the training environment for space flight missions also carries some inherent risk. Vacuum chambers, diving operations, flying operations, suited flight profiles, survival training, and other types of training may have similar risks and concerns; thus, training environments may also be discussed within the levels of care.

4.1.1. Level of Care Zero

No perceived threat to health or life exists, and there is no planned medical support to mitigate any risks. There are currently no space vehicles or missions in human space flight with this level of care; however, there are training situations that fall into this category. Level of Care Zero

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does not require any special medical support. Examples for Level of Care Zero are nonhazardous training activities. A T-38 flight, although hazardous in respect to aviation, does not have an overwhelming medical threat or risk. Thus, it has a survival kit but does not have medical kits as part of perceived medical risk mitigation.

4.1.2 Level of Care One

Little perceived threat to health or life exists during training or that portion of the mission where medical intervention would be allowed.

The relatively short time and distance to definitive care allows for first-aid implementation without more advanced care. Level of Care One requires a minimum of first-aid capability and implementation plans for follow-on medical support.

Level of Care One shall be provided for survival training and transfer missions to vehicles in LEO or for sub-orbital flights.

4.1.3 Level of Care Two

A moderate level of risk exists that personnel may experience medical problems during training or that portion of the mission.

4.1.3.1 Preventive strategies shall be used to reduce the risk.

4.1.3.2 Intervention strategies shall be used to reduce the risk to an acceptable level with return to Earth available for more serious illness/injuries.

4.1.3.3 Level of Care Two shall provide for clinical diagnostics and ambulatory care capability in addition to basic life support.

In addition to routine ambulatory care, medications or equipment would be used to support contingency emergencies, such as toxic exposures. The relatively short mission duration eliminates the need for medical hardware to evaluate long-term changes due to microgravity.

4.1.3.4 Level of Care Two shall be provided for crews in LEO for less than 30 days.

4.1.4 Level of Care Three

A moderate to high level of risk exists that personnel may experience medical problems during training or that portion of the mission.

4.1.4.1 Preventive strategies shall be used to a greater degree to reduce the overall risk.

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4.1.4.2 Intervention strategies shall be used to reduce the risk to an acceptable level, including an increased level of advanced care in the form of medications or equipment to include limited advanced life support, trauma care, and limited dental care.

The ability to sustain a critically ill or injured patient for any length of time is limited by consumables, training, and vehicle constraints.

4.1.4.3 Plans shall be available for transport to Definitive Medical Care Facilities (DMCF) upon return to Earth.

4.1.4.4 Return to Earth capability shall be available for more serious illness/injuries on orbit, when feasible.

It is also expected that all rescue crews that support launch and landing contingencies can provide this level of care.

4.1.4.5 Level of Care Three shall be provided for space flight crews that are engaged in missions outside of LEO, but of a short duration, e.g., lunar/planetary/missions equal to or less than 30 days.

4.1.5 Level of Care Four

A moderate to high level of potential risk exists that personnel may experience medical problems on orbit. Risk to the mission is greater for medical issues beyond routine ambulatory medicine.

4.1.5.1 Preventive strategies shall be used to a greater degree to reduce the overall risk.

The ability to support chronic illness is limited.

4.1.5.2 Intervention strategies shall be used to reduce the risk to an acceptable level, including increasing levels of advanced care in the form of medications, equipment, training, or consumables over and above previous levels.

4.1.5.3 The scope of medical care available shall be limited or triaged because of availability of supplies, consumables, or mission risk.

Return to Earth is not readily available and takes days, not hours, for more serious illness/injuries. Impact to overall mission is greater.

4.1.5.4 Level of Care Four shall be provided for lunar/planetary (destination surface segment) missions greater than 30 days but equal to or less than 210 days, as well as missions in LEO greater than 30 days, e.g., ISS.

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4.1.6 Level of Care Five

A high level of potential risk exists that personnel may experience medical problems on orbit at some time during the mission.

4.1.6.1 Preventive strategies shall be used to a greater degree to reduce the overall risk.

The ability to support chronic illness is limited.

4.1.6.2 Intervention strategies shall be used to reduce the risk to an acceptable level, including increasing levels of autonomous advanced care in the form of medications, equipment, training, or consumables over and above those for previous levels.

4.1.6.3 The training and skill of the caregiver shall be at the physician level, because of the exclusively autonomous nature of the mission.

4.1.6.4 The scope of medical care available shall be limited or triaged because of availability of supplies, consumables, or mission risk.

Return to Earth is not a viable option for more serious illness/injuries. Impact to overall mission is greater.

4.1.6.5 Level of Care Five shall be provided for lunar/planetary missions greater than 210 days.

4.1.7 Termination of Care

NASA shall have a policy and procedures for termination of care.

4.2 Standards for Human Performance

4.2.1 Overview

To support the Exploration Vision and to guide and focus efforts to protect the health of space-faring crews, space flight health standards for human performance have been developed. These standards provide a declaration of acceptable medical risk from the deleterious health and performance effects of space flight 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 requirements and aid in medical decision making during space missions.

The standards 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 standards. The process used for setting the standards was modeled on

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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.

These standards shall be periodically and regularly reviewed.

The standards may be updated as new evidence emerges. Additional standards may be developed as the need arises or is identified.

Appendix F in this Standard provides additional information on the content of the standards and supporting information that can help guide actions to address them.

4.2.2 Types of Standards

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

4.2.2.2 Space Permissible Exposure Limits (SPEL) - Quantifiable limit of exposure to a space flight factor over a given length of time, e.g., lifetime radiation exposure. Physical/chemical agent measured.

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

4.2.3 Fitness-for-Duty Aerobic Capacity Standard

4.2.3.1 Crewmembers shall maintain a pre-flight maximum aerobic capacity (VO_{2max}) at or above $32.9 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$.

4.2.3.2 The in-flight aerobic capacity shall be maintained, either through countermeasures or work performance, at or above 75 percent of the pre-flight value and no less than $32.9 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$, as determined by either direct or indirect measures.

4.2.3.3 The post-flight reconditioning shall be aimed at achieving a VO_{2max} at or above the crewmember's pre-flight values.

4.2.4 Fitness-for-Duty Sensorimotor Standard

4.2.4.1 Pre-flight sensorimotor functioning shall be assessed and be within normal values for age and sex of the astronaut population.

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4.2.4.2 In-flight Fitness-for-Duty standards shall be guided by the nature of mission-associated high-risk activities.

4.2.4.3 In-flight Fitness-for-Duty standards shall be assessed using metrics that are task specific.

4.2.4.4 Sensorimotor performance limits for each metric shall be operationally defined.

4.2.4.5 Countermeasures shall maintain function within performance limits.

4.2.4.6 Post-flight reconditioning shall be monitored and aimed at returning to baseline sensorimotor function.

4.2.5 Fitness-for-Duty Behavioral Health and Cognition Standard

4.2.5.1 Pre-flight, in-flight, and post-flight crew behavioral health and crewmember cognitive state shall be within clinically accepted values as judged by behavioral health evaluation.

4.2.5.2 End-of-mission assessment and treatment for crewmember cognitive state shall include cognitive assessment, monitoring and, as needed, transitioning the crewmember back to pre-flight values.

4.2.5.3 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.

4.2.5.4 The planned number of hours for completion of critical tasks and events, workday, and planned sleep period shall have established limits to assure continued crew health and safety.

4.2.6 Fitness-for-Duty Hematology and Immunology Standard

4.2.6.1 Pre-launch hematological/immunological function shall be within normative ranges established for the healthy general population.

4.2.6.2 In-flight countermeasures shall be in place to sustain hematological/immunological parameters within the normal range as determined by direct or indirect means.

4.2.6.3 Countermeasures and monitoring shall be developed to 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.

4.2.6.4 Post-flight assessment and treatment shall be aimed at returning to pre-flight baseline.

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4.2.7 Permissible Outcome Limit for Nutrition Standard

4.2.7.1 Pre-flight nutritional status shall be assessed and any deficiencies mitigated before launch.

4.2.7.2 In-flight nutrient intake shall be no less than 90 percent of the calculated nutrient requirements, based on an individual's age, sex, body mass (kg), height (m), and an activity factor of 1.25.

4.2.7.3 In-flight nutritional status shall be assessed and recommendations/countermeasures applied for any decrements below predetermined values.

4.2.7.4 Post-flight nutritional assessment and treatment shall be aimed at returning to baseline.

4.2.8 Permissible Outcome Limit for Muscle Strength Standard

4.2.8.1 Pre-flight muscle strength and function shall be within normal values for age and sex of the astronaut population.

4.2.8.2 Countermeasures shall maintain in-flight skeletal muscle strength at or above 80 percent of baseline values.

4.2.8.3 Post-flight reconditioning shall be aimed at returning to baseline muscle strength.

4.2.9 Permissible Outcome Limit for Microgravity-Induced Bone Mineral Loss Performance Standard (Baseline with Calculated T-Score)

4.2.9.1 Crewmembers' pre-flight bone mass Dual Energy X-ray Absorptiometry (DXA) T scores shall not exceed -1.0 (-1.0 Standard Deviation (SD) below the mean bone mineral density (BMD)).

4.2.9.2 Countermeasures shall be aimed at maintaining bone mass in-flight consistent with outcome limits.

4.2.9.3 The post-flight (end of mission) bone mass DXA T score shall not exceed -2.0 (-2.0 SD below the mean BMD).

4.2.9.4 Post-flight reconditioning shall be aimed at returning bone mass to pre-flight baseline.

4.2.10 Space Permissible Exposure Limit for Space Flight Radiation Exposure Standard

4.2.10.1 Planned career exposure to ionizing radiation shall not exceed 3 percent Risk of Exposure-Induced Death (REID) for cancer mortality at a 95 percent confidence level to limit the

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cumulative effective dose (in units of Sievert) received by an astronaut throughout his or her career.

Appendix F.9 in this Standard contains supporting material for the radiation standard.

4.2.10.2 Planned radiation dose shall not exceed career and short-term limits as defined in table 1, Dose limits for Short-Term or Career non-cancer Effects (in mGy-Eq. or mGy).

Table 2, RBE for Non-Cancer Effects^a of the Lens, Skin, BFOs, and Circulatory Systems contains Relative Biological Effectiveness (RBE) values for the lens, skin, Blood Forming Organs (BFOs) and circulatory systems. Note that while the Gray Equivalent quantity is used to limit these non-cancer effects (table 1), the RBE for Central Nervous System (CNS) non-cancer effects is largely unknown and, therefore, a physical dose limit (mGy) is used, with an additional Permissible Exposure Limit (PEL) requirement for particles with charge $Z > 10$ (table 1). Appendix F.9 in this Standard contains supporting material for the radiation standard.

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

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

| Organ | 30-day limit | 1-Year Limit | Career |
|------------------------|--------------|--------------|----------------|
| Lens* | 1,000 mGy-Eq | 2,000 mGy-Eq | 4,000 mGy-Eq |
| Skin | 1,500 | 3,000 | 6,000 |
| BFO | 250 | 500 | Not applicable |
| Circulatory System** | 250 | 500 | 1000 |
| CNS*** | 500 mGy | 1,000 mGy | 1,500 mGy |
| CNS*** ($Z \geq 10$) | - | 1,00 mGy | 2,50 mGy |

*Lens limits are intended to prevent early (<5 yr) 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 yr) 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.

***CNS limits should 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.

Table 2—RBE for Non-Cancer Effects^a of the Lens, Skin, BFO, and Circulatory Systems

| Radiation Type | Recommended RBE ^b | Range |
|----------------------|------------------------------|-------|
| 1 to 5 MeV neutrons | 6.0 | (4-8) |
| 5 to 50 MeV neutrons | 3.5 | (2-5) |
| Heavy ions | 2.5 ^c | (1-4) |
| Proton > 2 MeV | 1.5 | - |

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- ^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.

4.2.10.3 Lifetime fatality risks for non-cancer circulatory and CNS diseases shall be limited as defined by career dose limits in table 1.

4.2.10.4 Exploration Class Mission radiation exposure limits shall be defined by NASA based on NASA-requested recommendations from the National Academy of Sciences, the Institute of Medicine, and the National Council on Radiation Protection (NCRP).

4.2.10.5 In-flight radiation exposures shall be maintained using the as low as reasonably achievable (ALARA) principle.

4.2.11 Fitness-for-Duty Orthostatic Hypotension Standard

All approved countermeasures (fluid loading and compression garments) shall be utilized to mitigate symptoms of orthostatic hypotension (presyncopal/syncopal symptoms) to prevent impacts to performance of critical mission tasks.

4.3 Health and Medical Screening, Evaluation, and Certification

a. A program of comprehensive health care shall be provided that minimizes undesirable health consequences and enables a healthy and productive crew to accomplish mission goals.

b. Requirements for the health, medical safety, and well-being of the crewmembers for each space flight program shall be established.

4.3.1 Initial Selection Requirements

The NASA Medical Standards for Crewmembers includes initial selection criteria approved by the Aerospace Medicine Board (AMB), the Chair, Medical Policy Board (MPB) and OCHMO.

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a. The initial medical screening, testing, and certification required for astronaut selection shall be conducted as outlined in the NASA Crewmember Medical Standards, Volume I, and JSC-27384, Behavioral Health and Performance Program Plan Definition and Implementation Guide.

b. Medical standards and procedures for this process shall be maintained and updated on a periodic basis through formal review involving the JSC AMB and NASA MPB.

Selection and waiver criteria differ for the different types of missions (long duration versus short).

4.3.2 Medical Certification and Evaluation

a. Crewmember certification medical examinations shall be performed periodically by the organization responsible for medical certification.

b. These evaluations shall be performed in accordance with the following documents:

(1) NASA Crewmember Medical Standards, Volume I (OCHMO 80771201MED).

(2) Medical Evaluation Documents (MED) Volume A – Medical Standards for ISS Crewmembers (SSP 50667).

(3) Medical Evaluation Documents (MED) Volume B – Preflight, In-flight, and Post-flight Medical Evaluation Requirements for Long-Duration ISS Crewmembers (SSP 50667).

(4) Medical Evaluation Documents (MED) Volume C – Medical Standards and Certification Procedures for Space Flight Participants (SSP 50667).

c. Waivers shall be approved through the JSC AMB process.

d. Waivers in excess of 6 months and permanent medical disqualifications shall be reviewed for approval by the MPB Chair.

4.4 Medical Diagnosis, Intervention, Treatment, and Care

a. Medical diagnosis, intervention, treatment, and care for illness and injury shall be available to all crewmembers.

b. Care on Earth shall be in accordance with current U.S. medical standards and managed by the Flight Medicine Clinic (FMC).

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c. Medical intervention and care for assigned crews shall be managed by the assigned flight surgeons.

d. In-flight medical intervention and care shall be available to all crewmembers and shall be provided as close to current U.S. medical standards as the program and mission allow.

e. The level of in-flight medical intervention and care to be provided for assigned crews shall be as described under the levels of care in section 4.1 of this Standard.

4.4.1 Training Section

a. A comprehensive medical training program shall be provided to support crew health during space flight.

b. Medical training to astronaut candidates, assigned crewmembers, flight surgeons (FSs), mission control support staff, and other appropriate Ground Support Personnel (GSP) shall be provided.

4.4.1.1 Astronaut Training

a. Beginning with the astronaut candidate year, general medical training shall be provided to the astronaut corps.

b. Topics such as first aid, cardiopulmonary resuscitation (CPR), altitude physiological training, carbon dioxide exposure training, familiarization with medical issues, procedures of space flight, and psychological training shall be addressed.

c. Supervised physical conditioning training shall be available.

4.4.1.1.1 Assigned Crew, Non-Crew Medical Officer Medical Training

a. Crewmembers who have received a mission assignment shall be provided with more detailed and specific medical training.

b. Health issues, space physiology, medical procedures, medical equipment, toxicology, and countermeasures shall be included during this training.

c. This shall be documented in specific crew training documents for the program.

4.4.1.1.2 Assigned Crew, Crew Medical Officer Medical Training

a. A minimum of two crewmembers per assigned crew shall be trained as Crew Medical Officers (CMOs).

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b. The CMOs shall receive specific training to function as the in-flight medical staff, which focuses on communications during a Private Medical Communication/Conference (PMC), diagnostics procedures, therapeutics procedures, medical equipment, use of the medical checklist, and anticipated medical contingencies.

4.4.1.2 Crew Surgeon Training

NASA and/or contractor FSs assigned to support the subject space program shall receive training and certification in accordance with a program-specific training plan such as JSC-26546, NASA International Space Station Flight Surgeon Training and Certification Plan.

For the subject program, this training includes courses such as mission controller certification, ACLS/ATLS, flight medicine procedures, aerospace physiology, space medicine, hyperbaric medicine, and emergency mishap response.

4.4.1.3 Medical Operations Flight Controller Training

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

4.4.1.4 Other Support Personnel Training

Supervised training programs shall be implemented for individuals who require knowledge of space medicine or flight medical procedures, such as flight directors, medical consultants, and/or other personnel deemed appropriate.

4.4.1.5 Emergency Medical Services (EMS)

a. Requirements shall be provided in the Program MORD or similar document and in a Program Requirements Document (PRD) or similar document to task outside agencies for EMS support and ensure its implementation.

b. The organization responsible for astronaut health shall certify training plans for EMS personnel who work launch operations and concur on training plans for organizations that have a specific EMS training plan in support of a NASA space flight program.

4.4.2 Pre-Flight

a. Pre-flight medical intervention and care shall be available to all crewmembers, to include Assisted Reproductive Technology (ART) if desired by the crewmember.

b. Flight crewmember training and testing in situations that can be hazardous to flight crewmember health shall be monitored by the Crew Surgeon (CS) or designee.

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c. Specific pre-flight standards outlined in section 4.2 shall be addressed in the Program MORD.

4.4.2.1 Pre-Flight Exercise

a. A supervised physical conditioning program shall be available to all crewmembers to assist in mission preparation.

b. Specific exercise testing/training activities shall be offered to crewmembers with mission-unique needs involving endurance, strength, and/or flexibility.

4.4.2.2 Psychological Mission Training

Specific pre-flight 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.

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. Recommendations to Flight Crew Operations Directorate (FCOD), as requested, to assist in crew assignment and composition.*
- d. Training for medical and other GSP as indicated in support of behavior and performance issues.*
- e. Cross-cultural training support as indicated for international missions.*

4.4.2.3 Physiological Adaptive Mission Training

Proven countermeasures designed to assist crewmembers with physiological training and preflight adaptation in preparation for space flight shall be provided.

4.4.2.4 Health Stabilization Program

a. A Health Stabilization Program (HSP) that includes screening and monitoring shall be in place during the preparatory stages of the mission.

b. The HSP shall reduce the likelihood of contracting an infectious disease before launch by limiting exposures.

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- c. Pre-flight immunization against infectious diseases shall be employed.

4.4.2.5 Circadian Shifting Operations and Fatigue Management

Support of crew schedule planning and operations shall be provided to include circadian entrainment, work/rest schedule assessment, task loading assessment, countermeasures, and input to special activity schedules.

4.4.2.6 Pre-flight Medical Evaluations

- a. To evaluate and certify medical fitness for flight, pre-flight medical evaluations of all crewmembers shall be conducted before launch.
- b. These evaluations shall be performed at adjusted time intervals according to the specific program requirements.

4.4.3 In-Flight

Specific in-flight standards outlined in section 4.2 shall be addressed in the Program MORD.

4.4.3.1 Risk Management and Data Integration

Crew health shall be monitored and medical data collected to accomplish the following purposes:

- a. Real-time assessment of crewmember health.
- b. Establishment of baseline health norms for space flight.
- c. Health trend analysis of individual crewmembers and identification of health risks.

4.4.3.2 Level of Medical Care

- a. Medical care shall be configured to optimize crew health and the success of the mission.
- b. The levels of care described in section 4.1 shall be used to develop the requirements for a space flight program or vehicle.

4.4.3.3 Private Medical Communication (PMC)

- a. A PMC shall be scheduled on a routine basis at a frequency dictated for short- or long-duration missions and detailed in the Program MORD.
- b. Medical information that is sent to the ground via spacecraft telemetry shall be supplemented through the use of the PMC.

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The PMC deals directly with medical problems and preventive medicine.

- c. Two-way private voice and video communication shall be planned for PMCs.

4.4.3.4 Periodic Health and Fitness Evaluation

- a. For long-duration space flight, a periodic health status evaluation shall be conducted to monitor the crewmember's health.

- b. The timeline and details of the periodic health status shall be documented in the Program MORD.

4.4.3.5 Countermeasures

- a. The capability to implement, monitor, and validate operational in-flight countermeasures shall be provided to mitigate undesirable physical, physiological, and psychological effects of space flight upon crewmembers.

- b. The requirements shall be documented in the Program MORD.

4.4.3.5.1 Physiologic

The ability to define and monitor acceptable in-flight physical/physiological parameters and provide pharmacologic and therapeutic countermeasures to maintain these parameters shall be provided.

4.4.3.5.2 General Health and Well Being

Countermeasures shall be provided to address issues of human factors and general crew health and well-being, including considerations for hygiene, privacy, nutrition, crew schedule, workload, Earth observation, and leisure activities.

4.4.3.5.3 Behavioral Health and Performance

- a. Provisions shall be made to implement appropriate psychological support programs for the crew, key ground personnel, and crew families throughout the mission.

- b. These provisions shall be detailed in the Program MORD.

These provisions may include the following:

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- (1) *Capability to monitor and assess psychological status, including Private Psychological Conferences (PPCs) with two-way video and/or voice communication scheduled at least bi-weekly for each crewmember.*
- (2) *Private Family Conferences (PFCs) with two-way video and/or voice communication scheduled at least weekly for each crewmember.*
- (3) *Crisis intervention as needed.*
- (4) *Capabilities for crew relaxation, recreation, entertainment, news services, and social communication and behavioral adaptation.*

4.4.3.6 Extravehicular Activity (EVA)

All EVAs shall be preceded by an assessment of medical fitness requiring concurrence by ground medical support personnel.

4.4.3.6.1 Decompression Sickness (DCS) Prevention

Nominal planned EVAs shall be performed using validated protocols that allow crewmembers to perform each EVA with a total risk of DCS ≤ 15 percent per person with 95 percent statistical confidence.

Validated protocols shall meet the following historical criteria for acceptance based on ground studies:

- a. DCS ≤ 15 percent (includes Type I and cutis marmorata).
- b. Grade IV VGE ≤ 20 percent.
- c. No Type II DCS.

This DCS standard applies to the EVA section only and does not cover planned decompressions of a vehicle where the whole crew would be exposed to the hypobaric environment.

4.4.3.6.2 Extravehicular Suit Monitoring

The extravehicular suit shall provide monitoring of suit parameters, physiological variables, and external environmental variables to crew and GSP.

4.4.3.6.3 Biomedical Data Availability

- a. EVA biomedical data shall be available to the crew and the MCC.
- b. Biomedical monitoring parameters shall be documented in the Program MORD.

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4.4.3.6.4 DCS Treatment

DCS treatment capabilities (appropriate increases in atmospheric pressure and adjunctive medical therapies) shall be included as a part of medical intervention and care when EVAs are considered part of the mission architecture.

4.4.3.7 Toxic Exposure Prevention, Protection, and Treatment

a. Engineering controls shall be used when possible as the first line in personal protection of crew.

b. Personal Protective Equipment (PPE) and treatment of crewmembers subject to potential toxic exposure shall be part of in-flight medical intervention and care during all space missions.

4.4.3.8 Stabilization and Transport

a. Medical intervention and care shall include the capability to stabilize and transport an ill or injured crewmember if feasible as determined by levels of care described in section 4.1 of this document.

b. Stabilization and transport shall be addressed in the Program Crew Health Concept of Operations and MORD.

4.4.3.9 Medical and Survival Kits

Requirements for vehicle medical kits (routine and survival) shall be documented in the Program MORD and be consistent with the capabilities described in the Program Health Care Concept of Operations.

4.4.3.10 Medical Operations Ground Support

4.4.3.10.1 Crew Health Monitoring

a. Crew health surveillance shall be performed during missions.

b. Personnel shall monitor critical flight activities, respond to contingencies, and take corrective medical action as necessary.

c. In addition to the program of routine crew health assessment, crew health monitoring shall be performed by JSC Space and Clinical Operations Division personnel during intense exercise, medical tests, EVAs, and hazardous flight operations where real-time decisions and action may be required.

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4.4.3.10.2 Recordkeeping

- a. The results of all crew health monitoring shall be kept in a permanent and easily retrievable format for trend analysis.
- b. There shall be a simple and rapid way to communicate the data to the records.
- c. The method for handling, storing, and transmission of crewmembers' medical health records shall be secured.

4.4.4 Post-Flight

- a. The post-landing timeline for crewmember activities shall be controlled by a program document.
- b. The medical safety of the crew during the post-flight phase shall be ensured by the organization responsible for astronaut health.
- c. Specific post-flight standards outlined in section 4.2 in this Standard shall be addressed in the MORD.
- d. This post-flight health care shall be provided to support reconditioning and to minimize the chance of illness or injury to the crewmember because of his or her deconditioned state.

4.4.4.1 Post-flight Medical Evaluations

- a. Medical evaluation and monitoring of crews shall be conducted by a flight surgeon immediately post-flight periodically until crew status is stable.
- b. Criteria for the immediate post-flight medical evaluation at the landing site shall be provided in the Program MORD.

4.4.4.2 Emergency Medical Services (EMS)

- a. Requirements shall be provided in the Program MORD or similar document and in a PRD or similar document to task outside agencies for EMS support and ensure its implementation.
- b. Training shall be certified by the organization responsible for astronaut health for EMS personnel who work launch and landing operations.

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c. Concurrence on training plans for organizations that have a specific EMS training plan in support of a NASA space flight program shall be obtained from the organization responsible for astronaut health.

4.4.4.3 Reconditioning

a. A post-flight crew reconditioning program shall be planned, coordinated, and implemented by the JSC Space and Clinical Operations Division, in cooperation with the FCOD and Mission Operations Directorate (MOD).

The post-flight reconditioning starts with crew egress at landing, and includes a guided, phased reconditioning protocol.

b. The individualized reconditioning program shall be specific to crewmember and mission type and duration.

The goals of the reconditioning program are as follows:

- (1) To ensure the health and safety of the returning crew.*
- (2) To actively assist the crew's return to full functional abilities and return-to-flight status.*
- (3) To actively assist in the crew's return to pre-flight fitness.*

4.4.4.4 Psychological Function

Provisions shall be made to implement appropriate psychological support programs as needed for the crew, key ground personnel, and the crew families following space flight.

These provisions may include post-flight behavioral health and cognitive assessments, monitoring, and psychological support to transition the crewmember back into work and family.

4.4.4.5 Post-flight Testing

a. Post-flight medical intervention and care shall be available to all flight crewmembers of space missions.

b. Post-flight medical intervention and care shall include the following:

- (1) Physical examinations.
- (2) Clinical laboratory tests.
- (3) Physical and psychosocial re-adaptation.
- (4) Treatment as required.

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- (5) Scheduled days off and rest periods.
 - (6) Circadian rhythm retraining.
 - (7) Nutrition assessment and support.
- c. The FS or designee shall monitor flight crewmember testing in situations that can be hazardous to the health of the flight crew.

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APPENDIX A

DOCUMENT MAP

A.1 Purpose and/or Scope

The purpose of this appendix is to provide guidance, made available in figure 1, Document Map.

A.2 Document Map

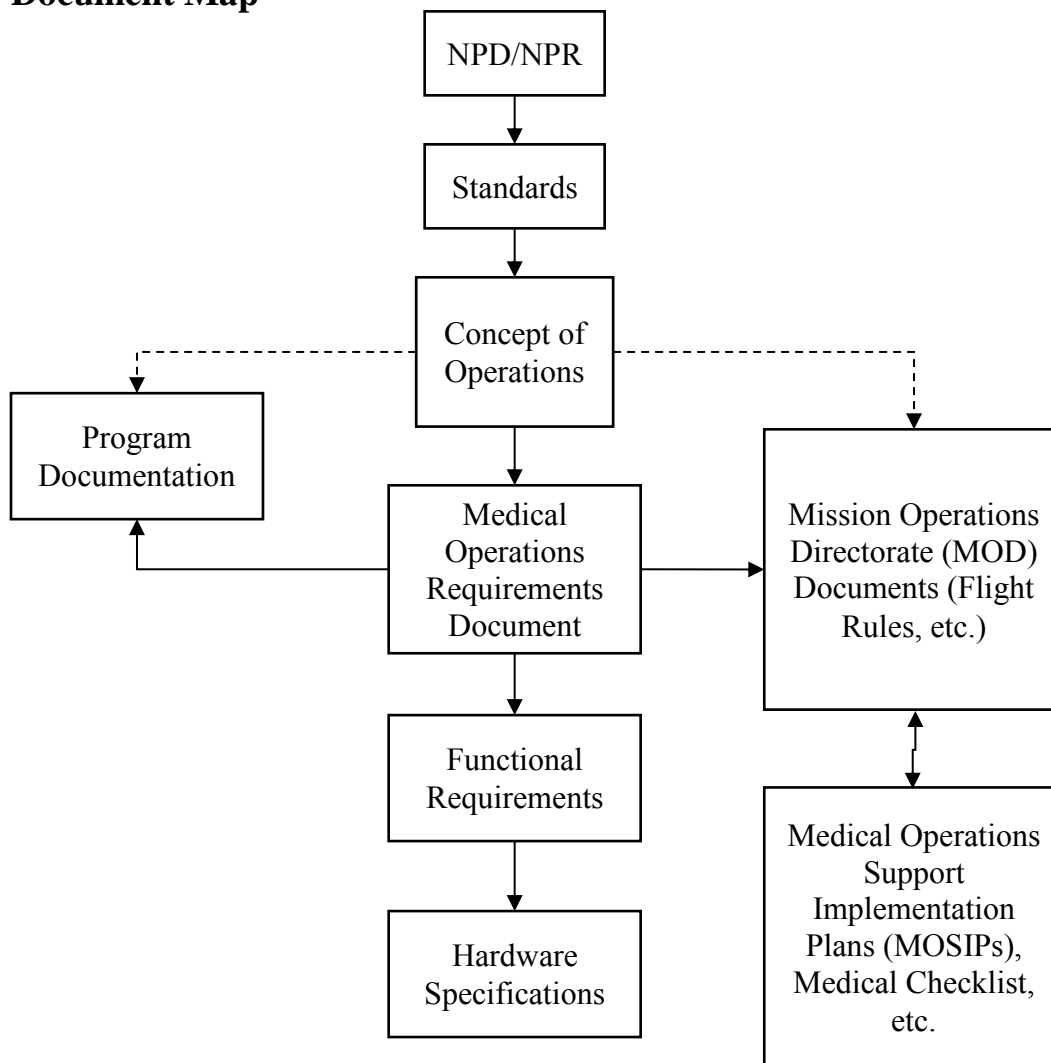


Figure 1—Document Map

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APPENDIX B

EXAMPLE OUTLINE OF A CONCEPT OF OPERATIONS

B.1 Purpose and/or Scope

This appendix provides guidance in the form of an example outline for a concept of operations.

B.2 Crew Health Concept of Operations for Exploration Missions

- Section I - Introduction
- General/Overview
- Purpose
- Scope
- Authority
- NASA Medical Authority Structure
- Risk
- Assumptions
- General Assumptions
- Crew Health Assumptions
- Countermeasure Assumptions
- Environmental Assumptions
- Section II - Pre-flight
- Crew Health
- Health Stabilization Program
- Countermeasures.....
- Physical Conditioning
- Environmental
- Air Quality/Toxicology
- Acoustics
- Microbiology
- Water Chemistry
- Radiation
- Section III - Launch
- Medical Support
- Countermeasures
- Environmental
- Section IV - In-flight/On-orbit
- General/Overview
- Medical/Physiological Considerations of Exploration Class Missions
- Space Motion Sickness
- Behavior and Performance Evaluation
- Decompression Illness

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- Neurovestibular
- Cardiovascular
- Bone
- Immune Response
- Muscle Alterations and Atrophy
- Nutrition
- Environmental Health Considerations of Exploration Class Missions
- Radiation
- Multi-Purpose Crew Vehicle (MPCV) Transfer Missions (ISS, Lunar, and To Be Determined Mars Transfer Vehicle)
- General/Overview
- Risks
- Matrix Overview
- MPCV
- Medical Intervention and Care
- Minimum Levels of Medical Care for Transfer Missions
- First Aid/Ambulatory/Basic Life Support
- Private Conferences
- Electronic Mail
- Countermeasures
- Environmental
- Air Quality/Toxicology
- Acoustics
- Microbiology
- Water Chemistry
- Radiation Ops
- EVA
- Lunar Sortie Mission
- General/Overview
- Risk
- Medical Intervention and Care
- Minimum Levels of Medical Care
- First Aid/Ambulatory/Basic Life Support
- Private Conferences
- Electronic Mail
- Countermeasures
- Environmental
- Air Quality/Toxicology
- Acoustics
- Microbiology
- Water Chemistry
- Radiation Ops
- Extravehicular Activity (EVA) Operations
- Lunar Mission with Destination Surface Segment

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- General/Overview
- Risk
- Medical Intervention and Care
- Minimum Level of Medical Care
- First Aid/Ambulatory/Basic Life Support
- Chronic Care
- Periodic Health and Fitness Evaluations
- Private Conferences
- Electronic Mail
- EVA Operations
- Countermeasures
- Environmental
- Air Quality/Toxicology
- Acoustics
- Microbiology
- Water Chemistry
- Radiation Ops
- Mars Missions
- Section V - Return
- Medical Intervention and Care
- Countermeasures
- Environmental
- Section VI - Landing and Crew Recovery
- Ground Support Operations - Medical Support
- General/Overview
- Nominal Landing Medical Support
- Section VII - Post-landing
- Medical Intervention and Care
- Return to Johnson Space Center
- Medical Assessment
- Rehab/Countermeasures/ Physical Conditioning
- Countermeasures
- Environmental
- Section VIII - Medical Selection, Certification, and Training
- Medical Selection and Certification
- Medical Exams
- Additional Medical Exams
- Behavioral Health
- Pre-flight Training
- Crewmember Training
- Hazardous Training
- EVA Training
- Crew Medical Training
- MPCV Missions

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- Lunar Sortie Mission
- Lunar Mission with Destination Surface Segment
- Countermeasures Training
- Pre-flight
- MPCV Missions
- Lunar Sortie Mission
- Lunar Mission with Destination Surface Segment
- Environmental Training
- Medical Flight Control Team Training
- Mars Missions
- Section IX - Off-Nominal Situations
- Launch
- Abort Medical Support
- Pad
- Coastal Waters
- Open Ocean
- Countermeasures
- Environmental
- In-flight/On-orbit
- MPCV
- Medical Intervention and Care
- Chronic Care
- Advanced Life Support
- Countermeasures
- Environmental
- Air Quality/Toxicology
- Acoustics
- Microbiology
- Water Chemistry
- Radiation Ops
- EVA
- Lunar Missions
- Lunar Sortie Mission
- Medical Intervention and Care
- Chronic Care
- Advanced Life Support
- Stabilization and Transport
- Countermeasures
- Environmental
- Air Quality/Toxicology
- Acoustics
- Microbiology
- Radiation Ops
- EVA

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- Lunar Mission with DSS
 - Medical Intervention and Care
 - Advanced Life Support
 - Stabilization and Transport
 - Countermeasures
 - Environmental
 - Air Quality/Toxicology
 - Acoustics
 - Microbiology
 - Water Chemistry
 - Radiation Ops
 - EVA
- Mars
- Return
 - Medical Intervention and Care
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APPENDIX C

EXAMPLE OUTLINE OF A MEDICAL OPERATIONS REQUIREMENTS DOCUMENT

C.1 Purpose and/or Scope

The purpose of this appendix is to provide guidance in the form of an example outline of a medical operations requirements document.

C.2 Example Outline of a Medical Operations Requirements Document

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APPENDIX D

RATIONALE FOR LEVELS OF CARE

D.1 Purpose and/or Scope

This appendix provides guidance in the form of rationale for levels of care.

D.2 Standard of Care and Level of Care

Medicine uses two phrases to describe care: the level of care that one can provide and the standard of care. These are not interchangeable terms. The term level of care refers to the amount and type of care to be rendered, based on perceived need and the ability of the provider. Standard of care is the benchmark and current clinical practices by which that care is provided.

For example, a first-aid station, the neighborhood ambulance, and the surgical hospital provide different levels of care. One does not go to the first-aid station or the firehouse to have an appendectomy, nor does one go to the surgical hospital for a simple bandage. Yet, each of these entities is held to a standard of care that is expected among similar platforms that provide the same level of care. For instance, an ambulance on the east side of town is held to the same standard as one on the west side.

D.3 Level of Care Zero

Rationale: The expectation of need for medical care is low, e.g., accidentally cutting oneself on a sharp edge while flying in the T-38. This is an unplanned and unforeseen injury, such that opportunistic treatment (using a handkerchief, glove, napkin, or available resource within the vehicle) is employed to stop the bleeding until further care is sought. The injury was not planned for, and the experience of flying the aircraft hundreds of times did not allow the foresight into the occurrence of this problem. Although this level of care is acceptable for the scenario given, human space flight has a history of certain medical maladies that are expected, with obvious risks that have to be mitigated.

D.4 Level of Care One

Rationale: In this category, the risk of medical maladies has been mitigated almost exclusively by preventive medicine. Routine first aid including bandages, anti-emetics, etc., is appropriate for a suborbital space flight. Vehicle up-mass constraints, training, and vehicle size may eliminate the possibilities of a more extensive system.

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D.5 Level of Care Two

Rationale: In this category, the care may be delivered by a CMO, and most major illnesses are mitigated by preventive medicine, e.g., screening. The medical care, however, becomes more robust and includes the ability to support an increased level of care in the form of medications or equipment. In addition to routine ambulatory care, medications or equipment can be used to support contingency emergencies such as anaphylaxis or toxic exposure, and routine diagnoses such as urinary retention, space motion sickness (SMS), ocular foreign bodies, etc. The relatively short mission duration eliminates the need for medical hardware to evaluate long-term changes related to microgravity. For example, ultrasound, Holter monitoring, and surgical capability are not necessary components of this medical suite.

D.6 Level of Care Three

Rationale: Preventive medicine is still employed as a risk mitigation strategy, but illness, injury, or deconditioning may still occur. More robust medications and equipment are added to the previous foundation of care. Although immediate life-saving care is available in the form of airway management and limited advanced life support, the ability to sustain a critically ill or injured patient for any length of time is limited by consumables, training, and vehicle constraints.

D.7 Level of Care Four

Rationale: Preventive medicine is the paramount risk mitigation strategy. However, advanced and ambulatory care is necessary. The additional risk has increased to ensure the survival of the remaining crewmembers (intubating a crewmember on the moon can use up the oxygen supply for the remaining crewmembers or increase the fire risk on ISS) so that triage is then necessary. Small portable diagnostic devices, such as a portable ultrasound or Portable Clinical Blood Analyzer (PCBA) may be carried. Although immediate life-saving measures are still to be available, such as an Automated External Defibrillator (AED) for ventricular defibrillation, the critical care needed after such an event is not guaranteed but rather is dependent on many variables such as consumables, risk to the other crew, and patient condition. For instance, a crewmember can be defibrillated within 3 minutes and saved. Conversely, after multiple defibrillations, intubation, and oxygenation, the patient may deteriorate and may thus exceed the ability to sustain or save the patient. The patient's care is thus triaged as required. Triage becomes much more important on long-duration Exploration Class missions.

D.8 Conversion from Ground-Reliant to Autonomous Care

In autonomous medical care concepts, the astronaut caregiver is self-sufficient in the immediate care phase and relies on Mission Control for consultation. Also, more than likely, an increase in the amount of ambulatory medications is needed to accommodate the longer duration. The ability to sustain a critically ill or injured patient for any length of time is limited by consumables, training, and vehicle constraints. The medical care system is also dependent on the means of return or availability of return (Soyuz, MPCV, or other vehicle).

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D.9 Level of Care Five

Rationale: The training and caliber of the caregiver is at the physician level, because of the autonomous nature of the mission. Advanced and ambulatory care is provided but expanded. Additional portable diagnostic devices and surgical equipment may be used to augment the advanced and ambulatory support packs but are limited by up- and down-mass, the vehicle, and the ability to pre-deploy such items. Despite the addition of a physician caregiver, consumables and survival of the remaining crewmembers dictate what resources can be expended on critical care for the ill or injured crewmember.

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APPENDIX E

MEDICAL STRATEGIES FOR SPACE FLIGHT MISSIONS

E.1 Purpose and/or Scope

The purpose of this appendix is to provide guidance in the form of medical strategies for space flight missions.

E.2 Definitions

E.2.1 Primary Prevention Strategies

Primary prevention management strategies seek to prevent the occurrence of an injury or illness through pre-flight screening, training, administrative controls, and control of the environment.

E.2.2 Secondary Prevention Strategies

Secondary prevention management strategies seek to prevent illness and injury or reduce the severity of injury through measures such as countermeasures, safety aids, and acute care.

E.2.3 Tertiary Prevention Strategies

Tertiary prevention management strategies seek to minimize complications of and disability from injury or illness through measures such as advanced medical care, medical treatments, and rehabilitation.

E.3 Implementation Strategies

E.3.1 Primary Strategies

Primary prevention during astronaut selection is implemented by the Space and Clinical Operations Division. Once selected, the astronaut is to be medically qualified to fly one of the NASA missions (short duration, long duration in LEO, or long duration beyond LEO).

E.3.2 Secondary Strategies

After astronauts have been selected for a program flight, secondary strategies are implemented for continuation of certifications for flight (long or short) and training certifications. The selection standards are broken down into the categories of short duration (less than 30 days in orbit), long duration (over 30 days in orbit), and space flight participant. For long duration, the standards may be further clarified such that few or no waivers are allowed for exploration missions, or a subset of the standards (Program Medical Standards Supplement), which are more

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restrictive, may be developed for certain programs. The requirement/notice for this is defined in the program-specific MORD. If further details are required, review the details in other appropriate documents (waiver guides) or program medical standard supplements. The MORD and/or waiver guide for each space flight program details the secondary medical strategies and requirements for that program. Implementation is explained in the Medical Concept document.

E.3.3 Tertiary Strategies

Program requirements and plans to support the astronauts during pre-flight, including training events, as well as during in-flight and post-flight, are implemented by the Space and Clinical Operations Division at JSC through Medical Operations. This includes but is not limited to providing a certified FS to accompany the astronauts during hazardous training events and be available during launch and landing. The MORD for each space flight program details the tertiary medical strategies and requirements for that program's in-flight mission. Implementation is explained in the Medical Operations Support Implementation Plans (MOSIPs).

E.3.4 Emergency Medical Services (EMS)

Requirements during launch and landing are documented in the MORD and MOSIP. On orbit, astronauts are provided with the capability to provide care as defined in the levels of care described in this Standard. Medical support at all primary landing sites is sufficiently uniform, without disparity between standards of care. If there is no Definitive Medical Care Facility that satisfies the level of care for emergency treatment, mobile or fixed medical suites are provided or engaged to raise the level of care to sufficient levels to protect crew health and afford the capability of resuscitation.

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APPENDIX F

RATIONALE FOR SPACE FLIGHT HEALTH STANDARDS FOR HUMAN PERFORMANCE

F.1 Purpose and/or Scope

The purpose of this appendix is to provide guidance in the form of rationale for space flight health standards for human performance.

F.2 Fitness-for-Duty Aerobic Capacity Standard

Maximal aerobic capacity (VO_{2max}) is the maximum capacity to transport and use oxygen during exercise and is the gold standard measurement of aerobic fitness. Individuals with higher aerobic capacity have a greater ability to perform aerobic work. Individuals cannot work for prolonged periods of time at VO_{2max} as it represents a maximal capability. Most people can work for sustained periods of time at 25-50 percent of their VO_{2max} .

During long duration spaceflight aerobic capacity degrades 15- 25 percent during the initial 1-3 weeks [3]. Recent observations on ISS show, on average, a 17 percent decline in VO_{2max} within the first month, a slight but not significant trend upwards during flight, and a 17 percent reduction measured 2 days after landing [4]. The current exercise strategy for maintaining aerobic fitness is cardiovascular exercise 6 days per week.

In-flight decreases in aerobic capacity most likely result from deconditioning as a result of a variety of factors, including physiological adaptation to microgravity, limitations of exercise equipment, and decreased intensity and/or duration of exercise. Decline in VO_{2max} with space flight is not inevitable and several crew members have completely maintained VO_{2max} across a mission duration of ~6 months [4]. To assess the risk adequately, VO_{2max} measurements, either actual or derived, via a validated methodology are required at regular intervals to assess aerobic fitness during early, middle, and late mission phases, as well as to assess for fitness to complete critical mission tasks as determined by the Design Reference Mission (DRM).

Given that the intent of NASA-STD-3001 is to inform requirements and vehicle design for a variety of vehicles and DRMs, the standards contained within focus on the human system providing a balance between human capability and hardware design, including but not limited to vehicle design and extravehicular suits. The Human Health and Performance Directorate has reviewed metabolic data from EVAs from the ISS and Shuttle and determined that an appropriate task-based aerobic capacity is at or above $32.9 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$.

Astronauts with greater aerobic capacity are capable of a higher work capacity, sustaining higher workloads over time both as a function of percent VO_{2max} and average sustainable metabolic rate [1] [2]. (See table 3, Aerobic Fitness and 8-hr Sustainable Work Capacity.) There are several

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other factors to consider beyond work capacity, but it was assumed that astronauts have the proper skill set, training and motivation to complete the job.

Table 3—Aerobic Fitness and 8-hr Sustainable Work Capacity*

| VO_{2max} (ml•min ⁻¹ •kg ⁻¹) | Sustainable Percent | Work Output (ml•min ⁻¹ •kg ⁻¹) | kcal/min |
|---|----------------------------|---|-----------------|
| Low (<35) | 25% | <8.7 | 3 |
| Average (45) | 33% | 15 | 5 |
| Above Average (50) | 40% | 20 | 7.5 |
| Highly Fit (>55) | 50% | >27.5 | 10 |

*Adapted from [1][2]

EVA was selected as the activity to contribute to the determination of VO_{2max} for this standard. The first step was to determine the expected workload and duration of an EVA. Once this value was determined, the minimum in-flight VO_{2max} was determined such that the expected workload is sustainable. It is expected that some in-flight deconditioning will occur (especially in the first few weeks), which would indicate crewmembers should have a pre-flight VO_{2max} higher than the required in-flight VO_{2max}.

Expected EVA metabolic rates for this analysis were determined based either on flight data or analog study data. The estimated microgravity data come from an unpublished database of Shuttle and ISS EVA metabolic rates and NBL training metabolic rates. Data used for the ISS scenario were the flight metabolic data from STS-114 through STS-135. These data were reported in kcal•hr⁻¹ and transferred into VO₂ (ml•min⁻¹•kg⁻¹) 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 percent of their in-flight VO_{2max} was used to calculate the required in-flight VO_{2max} minimum. Pre-flight recommendations are provided given the historical experience showing declines of 15-25 percent in VO_{2max} but are not required as long as the in-flight VO_{2max} of 32.9 ml•min⁻¹•kg⁻¹ can be maintained. (See table 4, Required Minimum In-Flight VO_{2max} and Pre-Flight VO_{2max} Recommendations.)

Table 4—Required Minimum In-Flight VO_{2max} and Pre-Flight VO_{2max} Recommendations

| Example Destination | Estimated Average VO₂ (ml•min ⁻¹ •kg ⁻¹) during EVA | In-Flight VO_{2max} Minimum (ml•min ⁻¹ •kg ⁻¹) | Pre-Flight VO_{2max} Recommendation (assuming an in-flight 15% decline) | Pre-Flight VO_{2max} Recommendation (assuming an in-flight 25% decline) |
|----------------------------|---|---|---|---|
| ISS | 9.87 | 32.9 | 38.7 | 43.8 |

This recommended in-flight VO_{2max} would also be sufficient to address the average peak EVA VO₂, which was 19.4 ml•min⁻¹•kg⁻¹ and even the average of the top 10 EVA peak VO₂ values, which was 32.3 ml•min⁻¹•kg⁻¹.

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As a result of forward work, a more accurate determination of VO₂ during EVA tasks for ISS and future DRMs may result in an update to the established minimum aerobic capacity standard.

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Additional information can be found in the following documents

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F.3 Fitness-for-Duty Sensorimotor Standard

Exposure to the microgravity conditions of space flight induces adaptive changes in sensorimotor function. During periods of adaptive change on initial exposure to microgravity and on return to

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a gravity environment, astronauts experience disturbances in sensorimotor function. These disturbances include spatial disorientation, SMS, alterations in gaze control, and post-flight postural instability and gait ataxia [1-5]. Importantly, sensorimotor disturbances are more profound as duration of exposure to microgravity increases. These changes can impact in-flight operational activities, including spacecraft landing, docking, remote manipulation, and EVA performance. In addition, post-flight postural and gait instabilities could prevent or extend the time required to make a nominal or emergency egress from a spacecraft, leading to compromised mission objectives.

Sensorimotor impairments may present as sudden performance decrements or failures. An individual sensorimotor baseline can be obtained on all exploration astronauts upon initial selection and repeated as clinically indicated and before space flight. Crews start missions in optimal condition. The nature of the requirements of duties, e.g., EVA, piloting and navigating tasks, and habitat tasks (experiment operations, human/computer interface tasks, and repair and maintenance tasks), and their criticality need to be considered when assessing crew condition. In addition, the operational environments to be encountered, e.g., microgravity (in-flight) and reduced gravity (planetary surface), also need to be considered. Application of the standards depends on the nature and duration of the mission and associated high-risk activities.

There are five different measures that can be used to examine the complex integration of sensory stimuli and motor responses. It is highly likely that data collection along one dimension/modality may affect or interact with data collection along another dimension/modality. Information on the five different measures is shown below.

1. General Sensory Motor status can be broken down as follows: significant health issues, or transient or resolving events, that interfere with activities; diminished vision, hearing, language ability, strength, or sensory function; impaired executive function; inability to see, speak, hear, ambulate, or move; and unconsciousness or diminished consciousness, or intractable pain.
2. Motion sickness can be broken down as follows: transient motion sickness with Graybiel Motion Sickness Severity Level of M IIa (<7 points), exacerbated or repetitive symptoms of motion sickness that are mission-impacting that exceed the Graybiel Motion Sickness Severity Level of M IIa (>7 points), and unresolved/incapacitating motion sickness.
3. Perception can be broken down as follows: transient illusions, any repetitive or persistent illusions with operational impact, and persistent illusions that significantly impair the crewmember's ability to perform or that pose a danger to the mission or crew.
4. Changes in gaze control and associated alterations in visual acuity should not exceed levels that impact performance of critical mission tasks.
5. Disturbances in postural equilibrium and gait control should not exceed levels that impact the ability to complete critical mission tasks.

The most common sensorimotor difficulties encountered in space flight are SMS and post-flight neurovestibular symptoms. SMS is routinely controlled with pharmacological countermeasures.

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The functional neurologic assessments listed above allow motor and sensory performance ratings to be applied such that the crewmember's inability to complete complex mission-critical tasks can be determined, based on neurologic decrement.

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F.4 Fitness for Duty Behavioral Health and Cognition Standard

Factors that impact behavioral health, cognition, and performance during space flight include psychosocial adaptation, including team coordination, cooperation, and communication; sleep and circadian rhythm disturbances; and individual health and well-being. Environmental and mission-related stressors, such as microgravity, isolation and confinement, radiation, mission duration, and workload, may also impact the behavioral health and performance of the crew.

In the experience of the international space community, including US and Russian space programs, behavioral health issues have resulted in early termination of missions, some incidents of depressive and anxiety states, degraded performance, and interpersonal friction and conflict. Efforts to mitigate loss of behavioral health have included pharmacologic and physical countermeasures, training, and adaptation support.

The following is an outline of those mitigation strategies that are currently utilized to prevent decrements in behavioral health and performance of the crew during a space flight mission. It should be noted current behavioral health support is provided across the three stages of space flight: before the mission (preparation and training), during the mission (when the crew is in space and receiving support), and after the mission is complete (repatriation and adaptation back to terrestrial life). These behavioral health support services fall within six broad categories: selection, training, in-flight psychological and neurobehavioral support, in-flight psychological

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and neurobehavioral monitoring, family psychological support, and repatriation. Details of each category are provided below.

(1) Selection:

- Selection:
 - Behavioral Health and Performance (BHP) provides an evaluation from a psychological perspective during the astronaut selection process and participates throughout selection process.
- Composition:
 - Although BHP does not currently facilitate composition assignments for crew flight selections, composition strategies to address technical and non-technical compatibility of the crew will be an integral part of the pre-mission process for future missions.

(2) Training:

- Provides needed training to ensure effective adaptation and performance both at individual and team level.
- Concerned with effectively handling stress, dealing with cultural differences, working as a team, optimizing sleep and circadian adaptation strategies, etc.

(3) In-Flight Psychological and Neurobehavioral Support:

- Private psychological conferences (PPCs) are currently provided; additional psychological support include crew care packages, crew support events, e.g., talk with movie star during mission, and other support services, e.g., movies, books, magazines, favorite TV shows.
- Individualized countermeasures for pre-flight and in-flight operations include scheduling recommendations that take into account task load, sleep history, and operation constraints; sleep education and training; and appropriately timed light-dark exposure. When needed, interventions such as cognitive behavioral therapy and pharmaceutical countermeasures are utilized.
- For missions beyond 6 months and/or beyond LEO, individualized countermeasures should be provided. The level and type of countermeasure support should match the requirements of the mission.

(4) In-Flight Psychological and Neurobehavioral Monitoring:

- The development of baselines established from behavioral health and cognitive assessment tools are critical to the development of operating (performance) and morbidity (medical) ranges.
- Cognitive testing is a medical requirement and is currently fulfilled by the monthly administration of the Spaceflight Cognitive Assessment Tool for Windows (WinSCAT). A preflight baseline is obtained for each astronaut. A monthly in-flight test allows a comparison to each astronaut's baseline. A traumatic injury or illness on orbit would dictate additional testing and assessment.
- For missions beyond 6 months and/or beyond LEO, minimally obtrusive measures that objectively evaluate psychological and behavioral states and integrate the

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information within the context of each mission, e.g., CO₂, sleep quantity/quality, work/rest schedule, should be provided.

(5) Family Psychological Support:

- Current program includes support for crewmember's families; examples of support include Private Family Conferences (PFCs).
- For missions beyond 6 months and/or beyond LEO, additional resources to support families, significant others, and friends and to facilitate crew-ground communication, should be provided.

(6) Repatriation:

Repatriation briefings are conducted pre-flight and normally 6 weeks before landing with the astronauts and their family members. Additional behavioral support is provided on as-needed basis to facilitate the repatriation and reintegration of the astronauts with their family and work lives.

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F.5 Fitness-for-Duty Hematology and Immunology Standard

During space flight, immune system changes occur that potentially decrease the body's ability to fight infections and control dormant viruses. Space flight factors that can alter immune response include exposure to microgravity; increased radiation exposure; exposure to hazardous chemicals; exposure to toxins, molds, and bacteria; and increased stress. These changes may result in increased health risks for crewmembers during long-duration space flight.

The standard establishes the boundaries of the clinical range that exposes the crewmembers to acceptable risk of immune and hematologic disorders. The critical value is defined as the level that represents a significant failure of the hematopoietic system and is associated with specific clinical morbidity. Evaluation and action by the appropriate health care team are indicated when values reach this level.

Actions that can be taken to facilitate good immunological/hematological status include implementing a quarantine period before launch; assuring immunizations are current, in accordance with the NASA Crewmember Medical Standards; employing environmental measures to reduce exposure and subsequent sensitization to allergens and particulate matter; and determining whether crewmembers were sensitized to new environmental agents during flight using pre- and post-flight hypersensitivity panels.

During the mission, hematological/immunological values are to remain within normative values established for the general population. Target parameters have to remain outside the critical values, defined as those levels of the target parameters that are associated with specific clinical morbidities.

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F.6 Permissible Outcome Limit for Nutrition Standard

Nutrition has been critical in every phase of exploration to date, from the scurvy that plagued earlier seafarers to polar explorers who died from under-nutrition or, in some cases, nutrient toxicities. In this regard, the role of nutrition in space exploration is no different, with the exception that, during space exploration, there is no opportunity to obtain food from the environment.

Nutritional assessments of Mir and ISS crews have documented a range of issues, including inadequate caloric intake, weight loss, and decrements in status of individual nutrients, even in cases where intake was adequate. For some nutrients, status appears to be declining, while in others, excess is a concern, e.g., protein, sodium, iron.

Key areas of clinical concern for long-duration space flight and Exploration Class missions include loss of body mass, bone and muscle loss, increased radiation exposure, and general inadequate food intake.

In developing this standard, the following factors were considered: nutritional/biochemical data from 3- to 6-month space flight, known terrestrial dietary reference intakes and clinically significant blood/urine marker levels, target range necessary for full function to carry out mission tasks, standard deviations from target range that are acceptable on Earth, and margin of safety needed to maintain the standard above the clinically significant range.

Nutrient deficiency (or excess) related to inadequate supply, inadequate stability, or increased metabolism and excretion can lead to illness and/or performance decrements. Nutritional status has to be adequate before flight to ensure healthy crews at the start of the mission.

In the general sense, the primary nutrition risk is having a viable and stable food system and, further, one that the crew is willing and able to consume. Having food is important, but having the right nutrient mix can be more critical than having food alone. The risk factors for nutrition fall into a tiered approach, as described below.

First, the risks to the food system are based on the development of a food system that contains the required amounts of all nutrients. The stability of these nutrients over an extended period of time is a risk, but even more critical is the impact of the spacecraft environment, especially radiation, on these foods and nutrients. Degradation of nutrients with ground-based radiation e.g., for preservation, is damaging to certain vitamins.

Second, adequate consumption of food by the crew is a critical risk. Many crewmembers on long-duration station missions have not consumed adequate amounts of food. On Exploration Class missions, food freshness, menu fatigue, stress, and other factors play a significant role in crew food consumption, health, and performance.

Last, even if the food system contains all required nutrients and the crew consumes it, the risk is high for altered metabolism, e.g., absorption, storage, utilization, excretion, to factor into nutritional requirements.

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F.7 Permissible Outcome Limit for Muscle Strength Standard

The impact to muscle performance as a result of the physiologic changes from human space flight and microgravity is well documented. Efforts to mitigate loss of strength and endurance have included exercise countermeasures. In spite of current on-orbit exercise regimens that include resistive and aerobic exercise 6 days per week, deconditioning still occurs.

Health issues related to skeletal muscle deconditioning include musculoskeletal injury. Retrospective epidemiological studies indicate musculoskeletal injury rates among Shuttle astronauts more than double during the mission period. The mission period includes pre-flight training and testing, in-flight activities, and post-flight testing. Crewmembers tend to have a higher incidence of musculoskeletal injury in the back during the post-flight phase, which may be related to the large losses shown in the postural muscles. Men had a higher incidence of injury than women in all sites and types. The highest incidence of injuries was in the ankle and back, pre- and post-flight, respectively.

The operational concern regarding reductions in skeletal muscle strength is that these health outcomes may result in performance decrements required for completing mission tasks and can have an unacceptable, and possibly catastrophic, impact to exploration mission objectives. The skeletal muscle deconditioning effects of space flight are considered environmentally adaptive, reversible, and without sequelae affecting quality of life. However, in the absence of occupational task specifications, clinical guidelines were used to define the threshold for acceptable muscle loss contained in the current standard. This threshold, the permissible outcome limit, is an alternative until task analyses can be completed. Therefore, consider this standard a placeholder until actual exploration tasks, suits, vehicles, and mission scenarios are defined. The preliminary permissible outcome limit for skeletal muscle strength is relative to the crewmember's pre-flight baseline levels, as it is assumed that assigned astronauts have the capacity to complete all mission objectives at the time of launch.

The work of Ploutz-Snyder, et al., validates a strategy for identification of functionally relevant lower body muscle strength and power thresholds for performance of simple mission-related

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tasks (table 5, Lower and Upper Body Muscle Performance Threshold Values for Functional Tasks). Of these sample tasks, seated egress (rising from a chair and walking) required the greatest strength, but it is recognized that crew will need to perform more demanding tasks. Forward work will include using the aforementioned strategy to define strength and power thresholds for more demanding tasks, including some tasks representative of the most demanding mission tasks, such as assisting an incapacitated crew member and emergency egress. The strength and power thresholds may help inform a future NASA muscle standard as part of forward work.

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Table 5—Lower and Upper Body Muscle Performance Threshold Values for Functional Tasks*

| Test/Performance Threshold | IKKE /BW (Nm /kg) | KEM IF (N/k g) | LPM IF (N/k g) | LPP/ BW (W/ kg) | LPW /BW (J/k g) | BPM IF (N/k g) | BPP /BW (W/ kg) | BPW /BW BPW /BW | Related Exploration Functional Strength Requirement |
|-----------------------------|-------------------|----------------|----------------|-----------------|-----------------|----------------|-----------------|-----------------|--|
| Upright Seat Egress | 1.9 | 5.9 | 17.8 | 17.6 | 78.8 | | | | <ul style="list-style-type: none"> • Leg Strength • Dynamic Strength • Arm Strength • Shoulder Strength |
| Supine Seat Egress | 1.8 | 5.7 | 13.7 | 14.6 | 72.4 | | | | <ul style="list-style-type: none"> • Leg Strength • Pull Strength • Push Strength • Shoulder Strength • Arm Strength • Dynamic Strength |
| Object Carry | 1.7 | 4.5 | 13.1 | 6.5 | 71.4 | 3.4 | 8.2 | 18.3 | <ul style="list-style-type: none"> • Leg Strength • Grip Strength • Dynamic Strength • Wrist Strength • Arm Strength • Shoulder Strength |
| Ladder Treadmill | 1.0 | 5.2 | 13.3 | 8.2 | 34.4 | | | | <ul style="list-style-type: none"> • Leg Strength • Shoulder Strength • Arm Strength • Hand Strength |
| Rise From Fall | 1.7 | 5.4 | 13.8 | 8.2 | 71.4 | | | | <ul style="list-style-type: none"> • Push Strength • Leg Strength • Arm Strength • Shoulder Strength |
| Hatch Opening | | | | | | 13.0 | 10.8 | 46.0 | <ul style="list-style-type: none"> • Leg Strength • Dynamic Strength • Torque Strength • Hand Strength • Grip Strength |
| Construction Activity Board | | | | | | 3.1 | 2.3 | 9.9 | <ul style="list-style-type: none"> • Leg Strength • Shoulder Strength |

*From Ryder et al., 2011

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IKKE: isokinetic knee extension
 KEMIF: knee extension maximal isometric force
 LPMIF: leg press maximal isometric force
 LPP: leg press power
 LPW: leg press work
 BPMIF: bench press maximal isometric force
 BPP: bench press power
 BPW: bench press work
 BW: body weight (including external load)

Definitive missions, tasks, vehicles, and suits are not yet characterized. Table 6, Example Exploration Functional Tasks, is the initial assessment but requires quantitative measures by task.

Table 6—Example Exploration Functional Tasks

| 1.1.1.1 Strength | Functional Basis |
|-------------------------|---|
| Pinch/Finger Strength | Fasten and release seatbelt, operate controls |
| Grip Strength | Handling knife, sky genie, pry bar |
| Push Strength | Open side hatch, push escape slide |
| Pull Strength | D-ring, quick disconnects, pull escape slide |
| Shoulder Strength | Lifting from sit, swing out of hatch opening onto slide |
| Arm Strength | Lifting from sit, pry bar |
| Dynamic Strength | Lifting from sit |
| Wrist Strength | Handling knife |
| Torque | Turn wheel on side hatch, pry bar |
| Lifting Strength | Lift escape slide, lift out of escape hatch |
| Hand Strength | Pry bar, sky genie |
| Leg Strength | Operate rudder, brakes, foot restraints |

In summary, these guidelines are considered preliminary and by default are conservative. This standard may be refined as specific information becomes available.

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F.8 Permissible Outcome Limit for Microgravity-Induced Bone Mineral Loss Performance Standard

Bone loss is a consistent finding of space flight and, for a 6-month mission, averages 1-percent loss per month at the lower spine and hip locations. Bone loss does show great variability among individual astronauts and between various bone locations. Countermeasures to prevent or mitigate bone loss include exercise, pharmacological agents, and nutrition. It is expected that partial gravity missions will have bone loss rates less or equal to those seen on ISS flights.

The World Health Organization (WHO) defines normal BMD as a T-score above -1, osteopenia as a T-score of -1 to -2.5, osteoporosis as a T-score below -2.5, and severe osteoporosis as a T-score below -2.5 in combination with previous fragility fracture (figure 2, Risk of Hip Fracture in Males using Standardized Total Hip BMD). Notably, these guidelines were developed for osteoporosis diagnosis in postmenopausal women and in men age 50 and older. Forward work is required to develop clinically meaningful guidelines for astronauts.

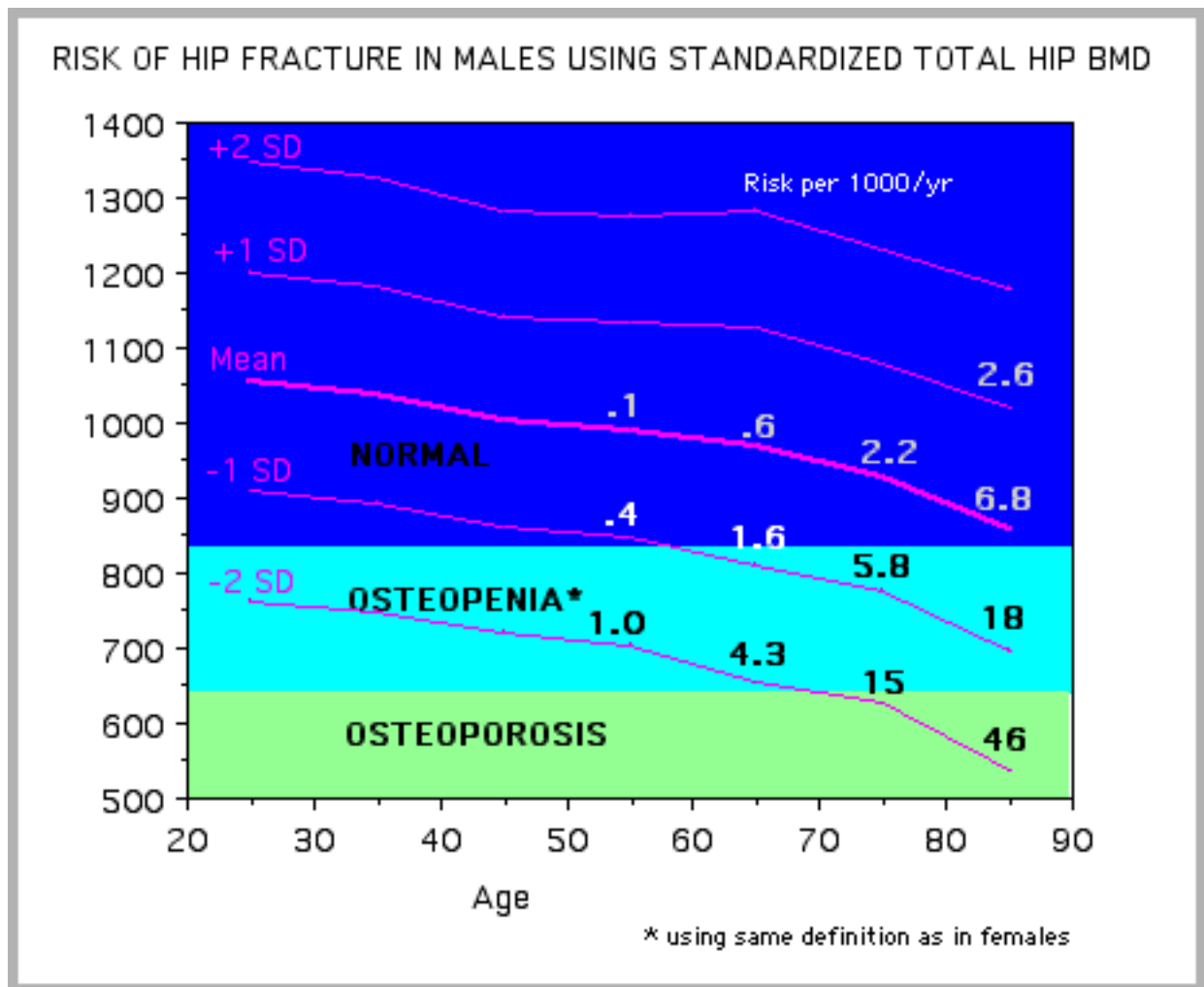


Figure 2—Risk of Hip Fracture in Males using Standardized Total Hip BMD

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World Health Organization Definitions of Osteoporosis Based on Bone Density Levels

Normal.

Bone Density is within 1 SD (+1 or -1) of the young adult mean.

Low Bone Mass.

Bone density is 1 to 2.5 SD below the young adult mean (-1 to -2.5 SD).

Osteoporosis.

Bone density is 2.5 SD or more below the young adult mean (> -2.5 SD).

Severe (established) osteoporosis.

Bone density is more than 2.5 SD below the young adult mean and there has been one or more osteoporotic fractures.

From National Osteoporosis Foundation Website

<http://www.nof.org/osteoporosis/bmdtest.htm>

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F.9 Space-Permissible Exposure Limits (SPEL) for Space Flight Radiation Exposure Standard

Radiation sources in space consist of the galactic cosmic rays (GCR), trapped radiation, and solar particle events (SPEs). As missions progress to outside LEO and away from the protection of Earth's magnetic shielding, the nature of the radiation exposures that astronauts encounter changes to include higher GCR and possible SPE exposures.

SPEL for radiation have the primary functions of preventing in-flight risks that jeopardize mission success and of limiting chronic risks to acceptable levels based on legal, ethical or moral, and financial considerations. Both short-term and career exposure limits are applied using assessments of the uncertainties in projection models with the space radiation environment defined by the program. Uncertainties are related to gaps in knowledge of biological effects of GCR, heavy ions, and the nature of SPEs. Although specific exposure limits are identified based on mortality risk, in all cases, decisions concerning vehicle, habitat, and mission design are made such that resulting crew radiation exposures are ALARA. As an operating practice, ALARA is a recognized NASA requirement. However, at the current time, the large uncertainties in GCR risk projections prevent an effective ALARA strategy for shielding approaches to be developed. For SPEs, uncertainties are smaller, acute risks are a concern, and ALARA is possible.

F.9.1 Risk Factors

Risk varies with the age and sex of the astronaut. Prior radiation exposures do not modify chronic risks for a specific mission but can reduce the available margin of individuals for specific missions. Possible risk factors related to genetic sensitivity are not included in current risk assessments. Mission risks vary over the approximately 11-year solar cycle, with higher GCR doses at solar minimum and higher likelihood of SPEs near solar maximum. Risks from an SPE are highest during EVA. Shielding can substantially reduce SPE doses and provide modest reductions for GCR.

F.9.2 Career Cancer Risk Limits

NASA uses the most recent OCHMO-approved version of the NASA Space Radiation Cancer Risk Model to perform REID assessments for astronauts. The most current model is maintained by the Radiation Health Office. Additional considerations for lifetime fatal risks from circulatory and CNS diseases are contained in dose limits for these tissues.

F.9.3 Cancer Risk-to-Dose Relationship

The relationship between radiation exposure and risk is age- and sex- specific related to latency effects and differences in tissue types, sensitivities, and life-spans between sexes. Table 7, Example Effective Dose Limits in Units of Sievert (mSv) for 1-Year Missions Resulting in 3-percent REID Point Value, Assuming an Ideal Case of Equal Organ Dose Equivalents for All Tissues and No prior Occupational Radiation Exposures, lists examples of career effective dose (E) limits for a REID = 3 percent for missions of 1-year duration or less. The 95th percentile confidence level using uncertainties in risk projections must be applied to these values. Limits

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for other career or mission lengths vary and can be calculated using the appropriate life-table formalism and projections in risk uncertainties.

Table 7—Example Effective Dose Limits in Units of Sievert (mSv) for 1-Year Missions resulting in 3-percent REID Point Value, Assuming an Ideal Case of Equal Organ Dose Equivalents for All Tissues and No Prior Occupational Radiation Exposures*

| Age (yr) | Females | | Males | |
|----------|--------------------------|---------------|--------------------------|---------------|
| | Avg. US Adult Population | Never-Smokers | Avg. US Adult Population | Never-Smokers |
| 30 | 0.44 Sv | 0.06 Sv | 0.63 Sv | 0.78 Sv |
| 40 | 0.48 | 0.70 | 0.70 | 0.88 |
| 50 | 0.54 | 0.82 | 0.77 | 1.00 |
| 60 | 0.64 | 0.98 | 0.90 | 1.17 |

*Reference table 6.2, Cucinotta, et al., 2013

F.9.4 Dose Limits for Non-Cancer Effects

Short-term dose limits are imposed to prevent clinically significant non-cancer health effects, including performance degradation, sickness, or death in flight. For risks that occur above a threshold dose, a probability of $<10^{-3}$ is a practical limit if more accurate methods than dose limit values are to be implemented. Lifetime limits for cataracts, heart disease, and damage to the CNS are imposed to limit or prevent risks of degenerative tissue diseases, e.g., stroke, coronary heart disease, striatum aging. Career limits for the heart are intended to limit the REID for heart disease to be below approximately 3 to 5 percent and are expected to be largely age and sex independent. Average life loss from gamma-ray-induced heart disease death is approximately 9 years.

F.9.5 The Principle of ALARA

The ALARA principle is a legal requirement intended to ensure astronaut safety. An important function of ALARA is to ensure that astronauts do not approach radiation limits and that such limits are not considered as tolerance values. ALARA is especially important for space missions in view of the large uncertainties in cancer and other risk projection models. Mission programs and terrestrial occupational procedures resulting in radiation exposures to astronauts are required to find cost-effective approaches to implement ALARA.

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F.10 Fitness-for-Duty Orthostatic Hypotension Standard

It is well documented that the cardiovascular system is affected by space flight. (Refer to Orthostatic Intolerance evidence book for review; <http://humanresearchroadmap.nasa.gov/evidence/reports/Orthostatic.pdf>)(1; 2; 12). One of the most important changes negatively impacting flight operations and crew safety is post-flight orthostatic intolerance leading to hypotension. Astronauts who have orthostatic hypotension are unable to maintain arterial pressure and cerebral perfusion during upright posture, and they experience presyncope or, ultimately, syncope. This may impair their ability to egress the vehicle after landing. This problem affects about 20-30 percent of crewmembers that fly short-duration missions (4-18 days)(4; 6; 14) and 83 percent of astronauts that fly long-duration missions (5).

An important point to make is that these survival analyses underreport the true rate of orthostatic intolerance on landing day, because crewmembers who are most severely affected on landing day are either not tested (and are thus not included in these calculations) or testing is delayed until the crewmember is sufficiently well to participate, often requiring fluid or pharmacological therapy. Thus, the true figures for presyncope following short-duration space flight and long-duration space flight are, in reality, higher than the commonly reported figures of 20-30 percent and 83 percent, respectively.

The etiology of orthostatic intolerance is complicated and multifactorial. While the decrease in plasma volume, secondary to the head-ward fluid shift that occurs in space, is an important initiating event in the etiology of orthostatic intolerance, it is the downstream effects and the physiological responses (or lack thereof) that may lead to this symptomology (5; 7-10). This is highlighted by the fact that while all crewmembers that have been tested are hypovolemic on landing day, only a fraction of them develop orthostatic intolerance and hypotension during stand/tilt testing.

While orthostatic intolerance is perhaps the most comprehensively studied cardiovascular effect of space flight, the mechanisms are still not well understood. Enough is known to allow for the implementation of some countermeasures, including fluid loading (3) and re-entry compression garments (11; 13). These, combined with post-landing compression garments and immediate access to medical care, mitigate the risk to acceptable levels. Note that post-landing compression garments are under development and have shown promise following short-duration flights. For future long-duration missions, it may be possible to combine the reentry suit and the post-flight garment with minimal additional effort.

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F.11. Decompression Sickness Prevention

F.11.1 Overview

It is well accepted that gas bubbles through some mechanism are the initial cause of the symptoms of DCS. Gas bubble formation and growth can potentially occur during decompressions from higher to lower ambient pressure in both divers and aviators or astronauts. Consequences of DCS can range from mild joint pain to seizures, paralysis, and death. The ISS and Shuttle programs selected an Earth nominal atmosphere, which served as a control for many of the experiments evaluating the effects of microgravity. When combining this atmosphere with the low-pressure spacesuit atmosphere required for EVA, DCS remains a significant risk. Past efforts to mitigate DCS have focused on achieving a safe and operationally feasible oxygen (O₂) prebreathe (PB) protocol. Although DCS risk has been greatly reduced through these PB protocols, it is at the expense of significant crew time and consumable usage. New developments should rely on an integrated DCS mitigation strategy from which to minimize DCS risk, while concurrently maximizing the crewmember work efficiency index.

Protocols are designed to reduce the risk of DCS to within acceptable limits. The NASA DCS Risk Definition and Contingency Plan (1998) (1) criteria specify acceptable limits as a total incidence of DCS ≤ 15 percent at a 95 percent confidence level, with < 20 percent Grade IV venous gas emboli (VGE) and 95 percent confidence level, and no Type II (serious) instances of DCS. These accept limits were specific for the many EVAs required for ISS construction, to guarantee that the ISS construction would not be hindered by DCS. It is likely that different limits will apply for future mission goals. Future exploration goals, which have different gravity levels, operational concepts, DCS treatment capability, and increased time to return to Earth in the event of serious DCS, may necessitate the development of new limits of acceptable DCS risk.

F.11.2 Predicting DCS

Many models of decompression stress have been developed based on statistical fitting of empirical data, mathematical modeling of biophysical principles, or a combination of both. However, limitations of the complete mechanistic understanding of DCS mean that existing models are generally applicable for estimating decompression stress only under conditions in which considerable empirical data already exist. Even small variations in pressure, duration, ascent and descent rates, breathing mixture, the sequence of decompressions, metabolic rate, or breaks in PB can have significant effects on observed DCS incidence that are not confidently predicted by models.

A fundamental axiom about DCS is that a transient gas supersaturation, also called over-pressure or pressure difference (ΔP), exists in a tissue region; the sum of all gas partial pressures in that region is greater than the ambient pressure opposing the release of the gas. Expressed as an equation, supersaturation exists when ΔP is positive:

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$$\Delta P = \left(\sum_{i=1}^n P_i - P_2 \right) \quad (\text{Equation 1})$$

where P_i = the dissolved gas tension of the i th gas of n species in the tissue and P_2 = the ambient pressure after depressurization. The potential for bubble nucleation and rate of bubble growth are a function of supersaturation.

F.11.3 Preventing DCS

To the extent that there is uncertainty in DCS risk, the life-threatening consequences of a severe case of DCS necessitates conservatism in the development, approval, and implementation of PB protocols. The result is that protocols may be longer than necessary to meet the agreed-upon level of acceptable risk. Longer PB protocols increase the unproductive crew time required before EVA and increase the mass of O_2 required because O_2 must be vented to vacuum during PB to remain within atmospheric flammability constraints.

One can reduce the ΔP in Eq(1) and, therefore, the $P(\text{DCS})$ by reducing P_i or increasing P_2 or some combination of both to achieve acceptable risk and operational efficiency. In space flight application, P_2 is suit pressure. Current suit technology, especially in the design of gloves, does not permit a high-pressure suit without increased fatigue and reduced mobility. So, reducing the risk of DCS by increasing suit pressure has significant operational limitations. The Exploration Atmospheres Working Group (2,3) determined that a reduction in P_i would drastically reduce O_2 PB time and recommended an atmosphere of 8 psi and 32 percent O_2 to minimize tissue P_{N_2} without significant hypoxia.

The above discussion focused on the classic Haldanean approach (4): reducing the amount of tissue nitrogen (N_2) to limit bubble growth. However, an emerging area of DCS prevention is also to hinder the transformation of tissue micronuclei into growing bubbles. The presence of gaseous micronuclei in the tissues permits DCS under modest depressurizations. Information about and evidence for tissue micronuclei come mostly from indirect observations. Application of a high-pressure spike reduces the number and size of micronuclei, as is evident from fewer bubbles or cases of DCS after a subsequent depressurization.

Flammability and long-term medical concerns mean that the pure O_2 environments used during Mercury, Gemini, and Apollo are no longer considered acceptable by NASA. Protocols used during the Shuttle program and currently in ISS missions are based on relevant data from comparable PB and decompression profiles assuming saturation at either 14.7 psi or 10.2 psi with an EVA suit pressure of 4.3 psi and an EVA duration of up to 8 hours. Furthermore, PB durations are based on an agreed-upon level of acceptable risk of DCS that itself was based upon characteristics of the Space Shuttle and ISS programs.

The architectures being developed by NASA for future exploration beyond LEO differ from previous vehicles and EVA systems in terms of vehicle saturation pressures, breathing mixtures, EVA frequency, EVA durations, and pressure profiles and will almost certainly differ in terms of the definition of acceptable DCS risk and in-situ DCS treatment capabilities. In particular, the

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use of suit ports, variable pressure EVA suits, intermittent recompressions, and possibly abbreviated purges with PB gas mixtures of less than 100-percent O₂ represent a paradigm shift in the approach to EVA with the potential of reducing EVA crew overhead and consumables usage by two orders of magnitude. The extent to which the potential benefits of the proposed approach to exploration EVA depend, in part, upon the development, validation, and implementation of an integrated DCS risk definition, mitigation, and treatment plan (5).

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APPENDIX G

REFERENCE DOCUMENTS

G.1 Purpose and/or Scope

The purpose of this appendix is to provide guidance and is made available in the reference documents listed below.

G.2 Reference Documents

| Document Number | Document Title |
|-----------------|---|
| | ACSM's Guidelines for Exercise Testing and Prescription, 6th Edition. 2000. Franklin BA, Whaley MH, Howley ET (eds). Philadelphia. Lippincott, Williams & Wilkins. 77p. |
| NASA-STD-3001 | NASA Space Flight Human Systems Standards, Volume 2: Human Factors, Habitability and Environmental Health |
| NPD 1000.3 | The NASA Organization |
| NPD 8900.1 | Medical Operations Responsibilities in Support of Human Space Flight Programs |
| NPD 8900.3 | Astronaut Medical and Dental Observation Study and Care Program |
| NPD 8900.5 | NASA Health and Medical Policy for Human Space Exploration |

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