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NASA SPACE FLIGHT HUMAN SYSTEM STANDARD

VOLUME 1: CREW HEALTH

MEASUREMENT SYSTEM IDENTIFICATION:
NONE

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FOREWORD

This standard is published by the National Aeronautics and Space Administration (NASA) to establish standards 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 due to space flight.

In this document, the Office of the Chief Health and Medical Officer establishes NASA's space flight crew health standards for the pre-flight, in-flight, and post-flight phases of human space flight. These standards 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 Space Shuttle and International Space Station programs, meet the intent and purpose of these standards currently, these standards may have implications for longer duration missions and missions with architectures and objectives outside of low Earth orbit. Although the standards 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.

This standard is approved for use by NASA Headquarters and NASA Centers, including Component Facilities.

Requests for information, corrections, or additions to this standard should be submitted via "Feedback" in the NASA Technical Standards System at http://standards.nasa.gov.

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Original Signed By

5 March 2007

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

Approval Date

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TABLE OF CONTENTS

SECTION		PAGE
DOCUMENT HISTORY LOG		2
FOREWORD		3
TABLE OF CONTENTS		5
LIST OF FIGURES		7
LIST OF TABLES		7
1.	**SCOPE**	8
1.1	Purpose	8
1.2	Applicability	9
1.3	Overview	10
2.	**APPLICABLE DOCUMENTS**	10
2.1	General	10
2.2	Government Documents	11
2.3	Non-Government Documents	11
2.4	Order of Precedence	11
3.	**ACRONYMS AND DEFINITIONS**	11
3.1	Acronyms and Abbreviations	11
3.2	Definitions	13
4.	**REQUIREMENTS**	13
4.1	Levels of Medical Care	13
4.1.1	Levels of Care	14
4.2	Standards for Human Performance	16
4.2.1	Overview	16
4.2.2	Types of Standards	17
4.2.3	Fitness-for-Duty Aerobic Capacity Standard	17
4.2.4	Fitness-for-Duty Sensorimotor Standard	18
4.2.5	Fitness-for-Duty Behavioral Health and Cognition Standard	18
4.2.6	Fitness-for-Duty Hematology and Immunology Standard	19
4.2.7	Permissible Outcome Limit for Nutrition Standard	19
4.2.8	Permissible Outcome Limit for Muscle Strength Standard	19
4.2.9	Permissible Outcome Limit for Microgravity-Induced Bone Mineral Loss Performance Standard (Baseline with Measured T-score)	20
4.2.10	Space Permissible Exposure Limit for Space Flight Radiation Exposure Standard	20

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TABLE OF CONTENTS, continued

SECTION		PAGE
4.3	Health and Medical Screening, Evaluation, and Certification	20
4.3.1	Initial Selection Requirements	21
4.3.2	Medical Certification and Evaluation	21
4.4	Medical Diagnosis, Intervention, Treatment, and Care	21
4.4.1	Training Section	22
4.4.2	Pre-flight	24
4.4.3	In-flight	26
4.4.4	Post-flight	29
5.	**GUIDANCE**	31
5.1	Reference Documents	31
Appendix A	**Document Map**	33
Appendix B	**Example Outline of a Concept of Operations**	34
Appendix C	**Example Outline of a Medical Operations Requirements Document**	39
Appendix D	**Rationale for Levels of Care**	43
Appendix E	**Medical Strategies for Space Flight Missions**	46
Appendix F	**Rationale for Space Flight Health Standards for Human Performance**	48

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LIST OF FIGURES

FIGURE		PAGE
1	Risk of Hip Fracture in Males Using Standardized Total Hip BMD	63

LIST OF TABLES

TABLE		PAGE
1	50th Percentile Values for Maximal Aerobic Power	18
2	CEV Functional Strength Requirements	60
3	Example career effective dose limits	66
4	Dose limits for short-term or career non-cancer effects	67

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NASA Space Flight Human System Standard
Volume 1: Crew Health

1. SCOPE

1.1 Purpose

NASA policy for establishing standards 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 standards 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 due to space flight. In this document, the Office of the Chief Health and Medical Officer establishes NASA's space flight Crew Health standards 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 standards presented in this document, NASA Space Flight Human System Standards, Volume I: Crew Health, are intended to complement the overall set of human standards for space flight, which also includes NASA Space Flight Human Systems Standards, Volume II: Habitability and Environmental Health; 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 standards 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 standards help ensure mission completion, limit morbidity, and reduce the risk of mortality during space flight missions. See Appendix A for an overview document map.

All standards are based on the best available scientific and clinical evidence, as well as operational experience from Apollo, Skylab, Shuttle, Shuttle/MIR (United Soviet Socialists Republic (USSR) Space Station), and International Space Station (ISS) missions. Standards 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 Medicine Division at the Johnson Space Center (JSC) for each space flight program and coordinated with the appropriate Program Manager for concurrence. See Appendix B for 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 Medicine 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. See Appendix C for an example outline of a MORD.

1.2 Applicability

These standards 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 Space Shuttle and ISS Programs, meet the intent and purpose of these standards currently, these standards may have implications for longer duration missions and missions with architectures and objectives outside of low Earth orbit (LEO). Although the standards 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 standards and technical requirements specified in this volume shall

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. 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 may be cited in contract, program, and other Agency documents as a technical requirement. Mandatory requirements are indicated by the word “shall,” statement of fact and descriptive material by “is,” and permission by “may” or “can.” Tailoring of, deviation from, or waivers to this standard for application to a specific program or project shall be approved by the NASA Chief Health and Medical Officer.

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1.3 Overview

The Space Flight Human System Standard, Volume I: Crew Health 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.

Volume 1, Crew Health 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 a guideline to develop requirements for maintaining the human system within normal operating parameters. To achieve this aim, the standards of the human system should be considered in vehicle design, mission architecture, countermeasures, and future directed research. Many of the standards 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 standards for these are cited, and further work is/may be required to define the standard more accurately.

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

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 of section 4. The latest issuances of cited documents shall be used unless otherwise approved by NASA Chief Health and Medical Officer. The applicable documents are accessible via the NASA Technical Standards System at http://standards.nasa.gov, directly from the Standards Developing Organizations, or from other document distributors.

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2.2 Government Documents

National Aeronautics and Space Administration

	NASA Crewmember Medical Standards, Volume I
JSC 25396	NASA Astronaut Medical Standards Selection and Annual Medical Certification Payload Specialist Class III
JSC 27384	Procedure Manual for the NASA Psychological Services Group

2.3 Non-Government Documents

None.

2.4 Order of Precedence

When this standard is applied as a requirement or imposed by contract on a program or project, the technical requirements of this standard take precedence, in the case of conflict, over the technical requirements cited in applicable documents or referenced guidance documents.

3. ACRONYMS AND DEFINITIONS

3.1 Acronyms and Abbreviations

ACLS	Advanced Cardiac Life Support
ACSM	American College of Sports Medicine
AED	Automated External Defibrillator
ALARA	As Low as Reasonably Achievable
AMB	Aerospace Medical Board
ART	Assisted Reproductive Technology
ATLS	Advanced Trauma Life Support
BFO	Blood Forming Organism
BMD	Bone Mineral Density
CBA	clinical blood analyzer
CDR	Commander
CEV	Crew Exploration Vehicle
CMO	Crew Medical Officer
CNS	Central Nervous System
CPR	Cardiopulmonary Resuscitation
CS	Crew Surgeon
DEXA T	Dual Energy X-ray Absorptiometry
DMCF	Designated Medical Care Facility
DSS	Destination Service Segment
EMS	Emergency Medical Services
EVA	Extravehicular Activity

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FAR	Federal Acquisition Regulation
FCOD	Flight Crew Operations Directorate
FFD	Fitness for Duty
FMC	Flight Medicine Clinic
FS	Flight Surgeon
g	Gravity
GCR	Galactic Comic Rays
HQ	Headquarters
HSP	Health Stabilization Program
ISS	International Space Station
JSC	Johnson Space Center
LEO	Low Earth Orbit
LET	Low Linear-Energy Transfer
LMS	Life and Microgravity Spacelab
kg	Kilograms
m	Meters
max (Subscript)	Maximum
MCC	Mission Control Center
MIR	USSR Space Station
min	minute
ml	milliliter
MOD	Mission Operations Directorate
MORD	Medical Operations Requirements Document
MOSIPs	Medical Operations Support Implementation Plans
MPB	Medical Policy Board
NASA	National Aeronautics and Space Administration
NCRP	National Council on Radiation Protection
NPD	NASA Policy Directive
NPR	NASA Procedural Requirements
Ops	Operations
PAWS	Performance Assessment Workstation
PFCs	Private Family Conferences
PMC	Private Medical Communication/Conference
POL	Permissible Outcome Limits
PRD	Program Requirements Document
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
STD	Standard
U.S.	United States
USSR	United Soviet Socialists Republic

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VO	Volume of oxygen
WHO	World Health Organization

3.2 Definitions

None.

4. REQUIREMENTS

4.1 Levels of Medical Care

Medicine typically uses two phrases to discuss care: (1) the Level of Care that one can provide and (2) the Standards of Care. These are not interchangeable terms. "Level of Care" refers to the amount and type of care rendered based on perceived need and the ability of the provider, whereas "Standard of Care" is the benchmark and current clinical practice by which that care is provided. See Appendix D for 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 distance 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, to include 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. Time required to return to Earth or other fallback location for more definitive medical treatment.

j. Terrestrial medical standards.

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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; and thus training environments may also be discussed within the Levels of Care.

4.1.1 Levels of Care

4.1.1.1 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 does not require any special medical support. Examples for Level of Care Zero are non-hazardous 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.

4.1.1.2 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, and 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 (basic life support) 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 (e.g., Shuttle or Crew Exploration Vehicle (CEV) to ISS) or for sub-orbital flights.

4.1.1.3 Level of Care Two

4.1.1.3.1 A moderate level of risk exists that personnel may experience medical problems during training or that portion of the mission. Preventive strategies shall be used to reduce the risk.

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

4.1.1.3.3 Level of Care Two shall be provided for crews in LEO for less than 30 days (e.g., stand alone Space Shuttle missions).

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4.1.1.4 Level of Care Three

4.1.1.4.1 A moderate to high level of risk exists that personnel may experience medical problems during training or that portion of the mission. Preventive strategies shall be used to a greater degree to reduce the overall risk.

4.1.1.4.2 Intervention strategies shall be used to reduce the risk to an acceptable level and shall include an increased level of advanced care in the form of medications or equipment.

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

4.1.1.4.4 Return to Earth capability shall be available for more serious illness/injuries on orbit, when feasible. It is also expected that all rescue crews, whether they be NASA sponsored or DoD sponsored, that support launch and landing contingencies can provide this Level of Care.

4.1.1.4.5 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).

4.1.1.5 Level of Care Four

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

4.1.1.5.2 The ability to support chronic illness is limited. Intervention strategies shall be used to reduce the risk to an acceptable level and shall include increasing levels of advanced care in the form of medications, equipment, training, or consumables over and above previous levels.

4.1.1.5.3 The scope of medical care available shall be limited or triaged due to 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.

4.1.1.5.4 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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4.1.1.6 Level of Care Five

4.1.1.6.1 A high level of potential risk exists that personnel may experience medical problems on orbit at some time during the mission. Preventive strategies shall be used to a greater degree to reduce the overall risk.

4.1.1.6.2 The ability to support chronic illness is limited. Intervention strategies shall be used to reduce the risk to an acceptable level and shall include increasing levels of advanced care in the form of medications, equipment, training, or consumables over and above those for previous levels.

4.1.1.6.3 The training and caliber of the caregiver shall be at the physician level, due to the exclusively autonomous nature of the mission.

4.1.1.6.4 The scope of medical care available shall be limited or triaged due to 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.

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

4.1.1.7 Termination of Care

4.1.1.7.1 NASA shall have a policy and procedures for termination of care, in the event the crewmember cannot be saved, or if continued treatment causes undue risk or peril to the remaining crew.

4.1.1.7.2 Topics such as disposition of the deceased shall be included in this plan.

4.2 Standards for Human Performance

4.2.1 Overview

In order 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 has 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 that

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used by the United States Occupational Safety and Health Administration, 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, and may be updated as new evidence emerges. Additional standards may be developed as the need arises or is identified.

Appendix F, Rationale for Space Flight Health Standards for Human Performance,, 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 have a pre-flight maximum aerobic capacity (VO_{2max}) at or above the mean for their age and sex (see American College of Sports Medicine Guidelines (ACSM)), in table 1 below).

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Table 1—50th Percentile Values for Maximal Aerobic Power (ml kg^{-1} min^{-1})

Age	Men	Women
20-29	43.5	35.2
30-39	41.0	33.8
40-49	38.1	30.9
50-59	35.2	28.2
60+	31.8	25.8

4.2.3.2 The in-flight aerobic fitness shall be maintained, either through countermeasures or work performance, at or above 75 percent of the pre-flight value, as determined by either direct or indirect measures.

4.2.3.3 The post-flight rehabilitation shall be aimed at achieving a VO_{2max} at or above the mean for age and sex (see ACSM's Guidelines in table 1).

4.2.4 Fitness-for-Duty Sensorimotor Standard

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

4.2.4.2 In-flight Fitness-for-Duty standards shall be guided by the nature of mission-associated high-risk activities, and shall be assessed using metrics that are task specific.

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

4.2.4.4 Countermeasures shall maintain function within performance limits.

4.2.4.5 Post-flight rehabilitation shall be 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 clinical psychological evaluation.

4.2.5.2 End-of-mission rehabilitation for crewmember cognitive state shall be aimed at transitioning the crewmember back to pre-flight values.

4.2.5.3 End-of-mission rehabilitation for behavioral health of the crewmember shall be aimed at 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.

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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., that level which 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 rehabilitation shall be aimed at returning to pre-flight baseline.

4.2.7 Permissible Outcome Limit for Nutrition Standard

4.2.7.1 Pre-flight nutritional status shall be assessed and any deficiencies mitigated prior to 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 Nutrition planning shall be aimed at maintaining a body mass and composition greater than 90 percent of pre-flight values.

4.2.7.4 Post-flight nutritional assessment and rehabilitation 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 rehabilitation shall be aimed at returning to baseline muscle strength.

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

4.2.9.1 Crewmembers' pre-flight bone mass Dual Energy X-ray Absorptiometry (DEXA T) score shall not exceed -1.0 (-1.0 Standard Deviation (SD) below the mean Bone Mineral Density).

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 DEXA T score shall not exceed -2.0 (-2.0 SD below the mean Bone Mineral Density).

4.2.9.4 Post-flight rehabilitation 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 for radiation shall not exceed 3 percent risk of exposure-induced death (REID) for fatal cancer.

4.2.10.2 NASA shall assure that this risk limit is not exceeded at a 95 percent confidence level using a statistical assessment of the uncertainties in the risk projection calculations to limit the cumulative effective dose (in units of Sievert) received by an astronaut throughout his or her career.

4.2.10.3 Exploration Class Mission radiation exposure limits shall be defined by NASA based on National Council on Radiation Protection (NCRP) recommendations.

4.2.10.4 Planned radiation dose shall not exceed short-term limits as defined in table 4 in Appendix F supporting material for the radiation standard.

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

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 by the Space Medicine Division at JSC.

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4.3.1 Initial Selection Requirements

a. The NASA Medical Standards for Crewmembers includes initial selection criteria approved by the Chair, Medical Policy Board (MPB). The initial medical screening, testing, and certification required for astronaut selection shall be conducted by the JSC Flight Medicine Clinic (FMC) and Aerospace Medical Board (AMB), as outlined in the NASA Crewmember Medical Standards, Volume I and JSC 27384, Procedure Manual for the NASA Psychological Services Group.

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

4.3.2.1 Annual Evaluations

a. Crewmember certification medical examinations shall be performed annually by the JSC FMC.

b. These evaluations shall be performed in accordance with NASA Crewmember Medical Standards, Volume I.

c. Payload specialists shall have a current certification according to JSC 25396, NASA Astronaut Medical Standards Selection and Annual Medical Certification Payload Specialist Class III.

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

4.3.2.2 Selection for a Mission

During the selection process for crewmember assignment, the JSC Space Medicine Division shall be consulted to ensure that the individual meets the medical standards for that particular mission.

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 FMC.

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c. Medical intervention and care for assigned crews shall be managed by the assigned flight surgeons beginning at a time designated by the Space Medicine Division.

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 document.

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, mission control support staff, and other appropriate ground support personnel (e.g., flight directors, consultants) shall be provided by the JSC Space Medicine Division.

4.4.1.1 Astronaut Training

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

b. Issues like 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 Crewmember 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 Crew Medical Officer Training

a. Each assigned flight crew shall have a minimum of two crewmembers designated 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 (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 flight surgeon(s) (FS) assigned to support the subject space program shall receive training and certification as defined in the Program, Medical Operations Flight Support 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) are required to complete the training and certification requirements outlined in the Program, Medical Operations Flight Support Training and Certification Plan. All medical operations MCC personnel shall be trained in the following:

a. MCC systems

b. Biomedical monitoring equipment

c. Vehicle life support systems

d. Flight operations

e. In-flight experiments

f. Extravehicular activities

g. Payloads

h. EMS

i. Crew Rescue

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 personnel deemed appropriate by JSC Space Medicine Division.

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4.4.1.5 Emergency Medical Services

a. Requirements shall be provided by JSC Space Medicine Division 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. Training shall be certified by the JSC Space Medicine Division for EMS personnel who work launch operations, and that Division shall 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) through the JSC FMC 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.

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

4.4.2.1 Crew Selection and Assignment

When operationally feasible, crew selection and assignment may consider the application of validated information concerning personality and its effect on crew composition.

4.4.2.2 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.

4.4.2.3 Psychological Mission Training

Specific pre-flight briefings and/or training shall be provided as appropriate to the commander (CDR), CMOs, crewmembers, key ground personnel (e.g., Flight Director and Astronaut Support Person), and crew families concerning the significant psychological and social phenomena that may arise during and after a mission. This may include the following:

a. Provision of recommendations and guidelines for family support activities

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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 ground support personnel as indicated in support of behavior and performance issues

e. Cross-cultural training support as indicated for international missions.

4.4.2.4 Physiological Adaptive Mission Training

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

4.4.2.5 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 in the week prior to launch by limiting exposures.

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

4.4.2.6 Circadian Shifting Operations

Support of crew schedule planning and operations shall be provided by the JSC Space Medicine Division to include circadian entrainment, work/rest schedule assessment, task loading assessment, and input to special activity schedules.

4.4.2.7 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.

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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. The medical capability on a mission shall primarily be prepared to handle those illnesses and injuries that will heal more rapidly with treatment or will become serious without treatment.

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. 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.

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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 (e.g., Flight Director and Astronaut Support Person), and crew families throughout the mission.

b. These shall be detailed in the Program MORD and may include the following:

(1) Capability to monitor and assess psychological status

(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

4.4.3.6 Extravehicular Activity (EVA)

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

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4.4.3.6.1 Extravehicular Suit Monitoring

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

4.4.3.6.2 Biomedical Data Availability

a. EVA biomedical data shall be available to the MCC medical ground support personnel.

b. Biomedical monitoring parameters shall be documented in the Program MORD.

4.4.3.6.3 Hyperbaric Oxygen Treatment

Hyperbaric treatment (stand alone, increase suit pressure, or equivalent) 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 Protection, Prevention, and Treatment

Personal protection and treatment of crewmembers subject to potential toxic exposure shall be included as 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. Transportation time begins when the crewmember is medically stable for transport and ends at delivery to a Definitive Medical Care Facility (DMCF).

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

c. For those situations where stabilization and transport are not possible or no longer required, procedures shall be incorporated into the Crew Health Concept of Operations and MORD to address a crewmember fatality.

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.

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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 by JSC Space Medicine Division personnel.

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 Medicine Division personnel during intense exercise, medical tests, EVAs, and hazardous flight operations where real-time decisions and action may be required.

4.4.3.10.2 Record Keeping

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. Signature by the JSC Space Medicine Division shall be on the program document.

c. The medical safety of the crew during the post-flight phase shall be ensured by the JSC Space Medicine Division.

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

e. This post-flight health care shall be provided to support rehabilitation and to minimize the chance of illness or injury to the crewmember due to his or her deconditioned state.

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4.4.4.1 Post-flight Medical Evaluations

a. Medical evaluation and monitoring of crews shall be conducted by NASA FSs or contractor FSs 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

a. Requirements shall be provided by JSC Space Medicine Division 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 JSC Space Medicine Division for EMS personnel who work launch and landing operations.

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 JSC Space Medicine Division.

4.4.4.3 Rehabilitation

a. A post-flight crew rehabilitation program shall be planned, coordinated, and implemented by the JSC Space Medicine Division, in cooperation with the FCOD and Mission Operations Directorate (MOD). The post-flight rehabilitation starts with crew egress at landing, and includes a guided, phased reconditioning protocol.

b. The individualized rehabilitation program shall be specific to crewmember and mission type and duration. The goals of the rehabilitation program are as follows:

(1) Ensure the health and safety of the returning crew

(2) Actively assist the crew's return to full functional abilities and return-to-flight status

(3) Actively assist in the crew’s return to pre-flight fitness

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4.4.4.4 Psychological Function

Provisions shall be made to implement appropriate psychological support programs as needed for the crew, key ground personnel (e.g., Flight Director and Astronaut Support Person), and the crew families following space flight.

4.4.4.5 Post-flight Testing

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

(1) Physical examinations

(2) Clinical laboratory tests

(3) Physical and psychosocial re-adaptation

(4) Treatment as required

(5) Scheduled days off and rest periods

(6) Circadian rhythm retraining

(7) Nutrition assessment and support

b. The FS or designee shall monitor flight crewmember testing in situations that can be hazardous to the health of the flight crew.

5. GUIDANCE

5.1 Reference Documents

	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: 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

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	Program
NPD 8900.5	NASA Health and Medical Policy for Human Space Exploration

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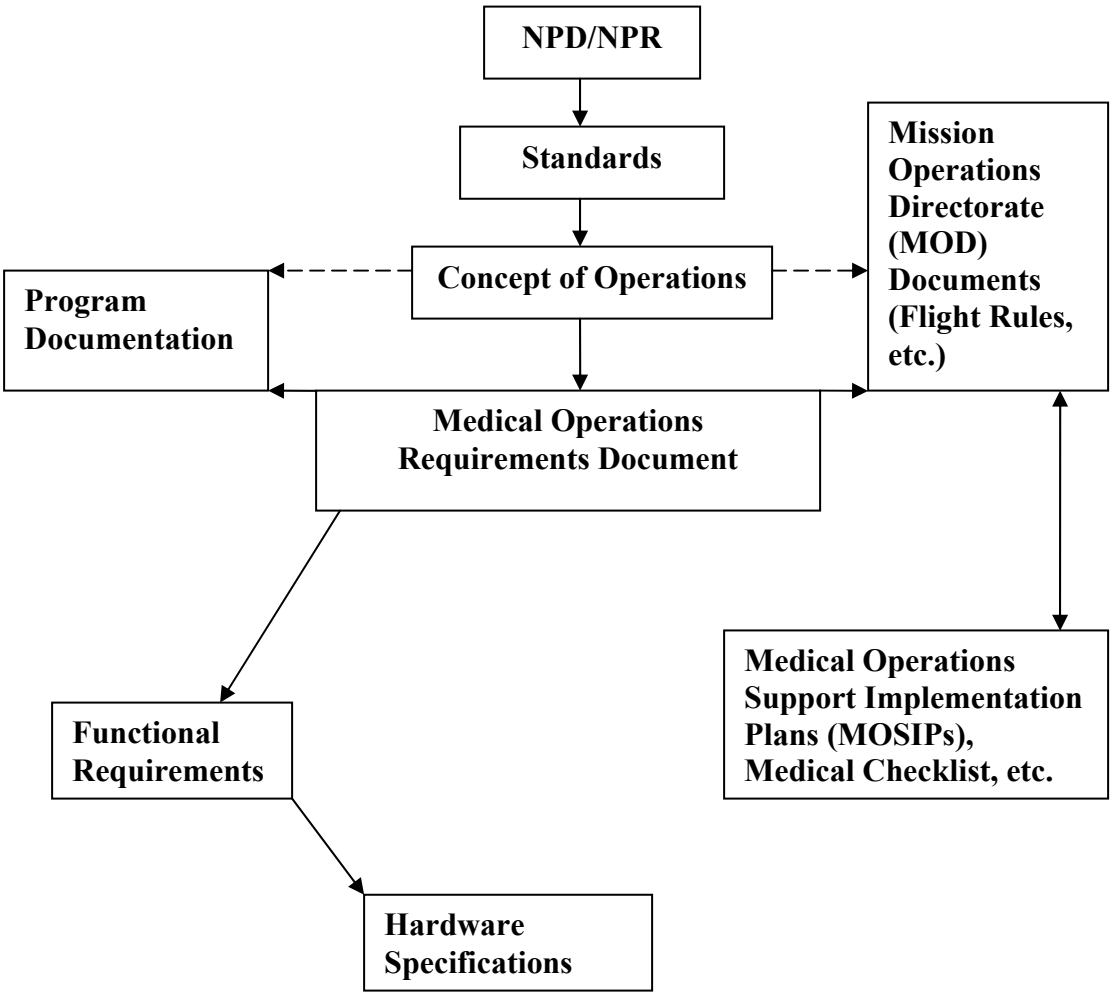
APPENDIX A

DOCUMENT MAP



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APPENDIX B
EXAMPLE OUTLINE OF A CONCEPT OF OPERATIONS

Crew Health Concept of Operations for Constellation 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.....
        Neurovestibular.....
        Cardiovascular.....
        Bone.....
        Immune Response.....
        Muscle Alterations and Atrophy.....
        Nutrition.....
    Environmental Health Considerations of Exploration Class Missions.....

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Radiation .....
Crew Exploration Vehicle (CEV) Transfer Missions (ISS, Lunar, and To Be Determined Mars Transfer Vehicle) .....
General/Overview .....
Risks .....
Matrix Overview .....
CEV .....
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 .....
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 .....

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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
CEV Missions
Lunar Sortie Mission
Lunar Mission with Destination Surface Segment
Countermeasures Training
Pre-flight
CEV Missions
Lunar Sortie Mission
Lunar Mission with Destination Surface Segment
Environmental Training
Medical Flight Control Team Training

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Mars Missions
Section IX - Off-Nominal Situations
Launch
Abort Medical Support
Pad
Coastal Waters
Open Ocean
Countermeasures
Environmental
In-flight/On-orbit
CEV
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
Lunar Mission with DSS
Medical Intervention and Care
Advanced Life Support
Stabilization and Transport
Countermeasures
Environmental
Air Quality/Toxicology
Acoustics
Microbiology
Water Chemistry

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Radiation Ops.....
EVA .....
Mars .....
Return.....
Medical Intervention and Care.....
Ill/Injured Crewmember Return.....
Environmental.....
Countermeasures.....
EVA .....
Landing and Crew Recovery .....
Medical Intervention and Care.....
Land .....
Coastal Waters .....
Open Ocean.....

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APPENDIX C
EXAMPLE OUTLINE OF A MEDICAL OPERATIONS REQUIREMENTS DOCUMENT

Title Page
Signature Page
Table of Contents
Section I - Introduction
1.1. General
1.2 Purpose
1.3 Scope
1.4 Authority
1.5 Applicability
1.6 Medical Authority Structure
1.6.1 U.S. Medical Authority Structure
1.6.1.1 HQ
1.6.1.2 AMB
1.6.2 U.S. Crew Care
1.6.2.1 Before Mission Selection
1.6.2.1.1 Flight Medicine Clinic
1.6.2.2 Following Mission Selection
1.6.2.2.1 Crew Surgeon Responsibility
1.6.2.2.1.1 Pre-flight
1.6.2.2.1.2 In-flight
1.6.2.2.1.3 Post-flight
1.6.3 International Medical Authority Structure (if applicable)
1.7 Privacy of Medical Information
1.7.1 Handling and Release of Medical Data
1.8 Risk Management and Data Integration
1.8.1 Risk Management
1.8.2 Data Integration
1.9 Medical Strategies for Space Flight Missions (See Appendix E in this document)
1.10 Levels of Care (Define the levels of care for the mission. See definitions in NASA Space Flight Human System Standard, Volume 1, Section 4.1)
1.11 Mission Duration
1.11.1 Pre-flight Medical Evaluations
1.11.2 In-flight Medical Evaluations
1.11.2.1 Private Medical Communications
1.11.2.2 Nominal Health and Fitness Evaluation
1.11.2.3 Extravehicular Activity Medical Requirements
1.11.2.3.1 Extravehicular Mobility Unit Monitoring
1.11.3 Post-flight Medical Evaluations

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Section II - Operations
2.1 Medical Intervention and Care
2.1.1 Pre-flight
2.1.1.1 Hazardous Training and/or Testing
2.1.2 In-flight
2.1.2.1 Minimum Level of Medical Care
2.1.2.1.1 First Aid/Ambulatory
2.1.2.1.2 Basic Life Support
2.1.2.1.3 Advanced Life Support (if required)
2.1.2.1.4 Stabilization and Transport
2.1.2.1.5 Chronic Care (if required)
2.1.2.1.6 Hyperbaric Oxygen Treatment (if required)
2.1.2.1.7 Toxic Exposure Protection, Prevention, and Treatment
2.1.2.1.8 Private Medical Conference
2.1.2.1.9 Periodic Health Status
2.1.2.1.10 Medical Operations Ground Support
2.1.2.1.10.1 Crew Health Monitoring
2.1.3 Post-flight
2.1.3.1 Rehabilitation
2.1.3.2 Testing

2.2 Environmental Health
2.2.1 Pre-flight
2.2.1.1 Water Quality
2.2.1.1.1 Water Quality Specifications
2.2.1.1.2 Water Monitoring Requirements
2.2.1.1.3 Water Decontamination Requirements
2.2.1.2 Air Quality
2.2.1.2.1 Off-gas Testing
2.2.1.2.2 Air Quality Specification
2.2.1.2.3 Air Monitoring Requirements
2.2.1.2.4 Air Decontamination Requirements
2.2.1.3 Microbiology
2.2.1.3.1 Microbiology Specifications
2.2.1.3.2 Microbiology Monitoring Requirements
2.2.1.3.3 Microbiology Decontamination Requirements
2.2.1.4 Radiation
2.2.1.4.1 Ionizing Radiation
2.2.1.4.1.1 Radiation Prediction, Monitoring, and Warning
2.2.1.4.1.2 Radiation Dose and Quality Monitoring
2.2.1.4.1.3 Crew Health Risk Assessment and Exposure Records
2.2.1.4.2 Non-Ionizing Radiation
2.2.2 In-flight
2.2.2.1 Water Quality
2.2.2.1.1 Water Quality Specifications

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2.2.2.1.2 Water Monitoring Requirements
2.2.2.1.3 Water Decontamination Requirements
2.2.2.2 Air Quality
2.2.2.2.1 Air Quality Specifications
2.2.2.2.2 Air Monitoring Requirements
2.2.2.2.3 Air Decontamination Requirements
2.2.2.3 Microbiology
2.2.2.3.1 Microbiology Specifications
2.2.2.3.2 Microbiology Monitoring Requirements
2.2.2.3.3 Microbiology Decontamination Requirements
2.2.2.4 Radiation
2.2.2.4.1 Ionizing Radiation
2.2.2.4.1.1 Radiation Prediction, Monitoring, and Warning
2.2.2.4.1.2 Radiation Dose and Quality Monitoring
2.2.2.4.1.3 Crew Health Risk Assessment and Exposure Records
2.2.2.4.2 Non-Ionizing Radiation
2.2.3 Post-flight
2.2.2.1 Water Quality
2.2.2.2 Air Quality
2.2.2.3 Microbiology
2.2.2.3.1 Microbiology Monitoring Requirements
2.2.2.3.2 Microbiology Decontamination Requirements
2.2.2.4 Radiation

2.3 Countermeasures System
2.3.1 Pre-flight
2.3.1.1 Crew Selection and Assignment
2.3.1.2 Psychological Training
2.3.1.3 Pre-flight Exercise
2.3.1.4 Physiological Adaptive Training
2.3.1.5 Health Stabilization Program
2.3.1.6 Crew Schedule Support Operations
2.3.1.6.1 Circadian Shifting Operations
2.3.2 In-flight
2.3.2.1 Physical/Physiological
2.3.2.2 General Health and Well-being
2.3.2.3 Behavioral Health and Performance
2.3.3 Post-flight
2.3.3.1 Re-adaptation
2.3.3.2 Physiological Function
2.3.3.3 Behavioral Health and Performance

2.4 Human Factors
2.4.1 Pre-flight
2.4.1.1 Acceleration Requirements

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2.4.1.2 Lighting Level Requirements
2.4.1.3 Maximum Noise Level Requirements
2.4.2 In-flight
2.4.2.1 Acceleration/Impact Requirements
2.4.2.2 Lighting
2.4.2.3 Noise Exposure Monitoring
2.4.3 Post-flight

2.5 Ground Support
2.5.1 Pre-flight
2.5.1.1 Normal Operations
2.5.1.1.1 Flight Control Team Exams
2.5.1.1.2 Hazardous Duty and Toxic Material Handling Certification
2.5.1.1.3 Personnel Reliability Program
2.5.1.1.4 Medical Consultants
2.5.1.1.5 Ground Occupational Medical Services
2.5.1.1.6 Medical Support of Hazardous Activities
2.5.1.1.6.1 Test Sites and Facilities
2.5.1.1.6.2 Medical Supervision of Pre-flight Experiments on Crewmembers
2.5.2 In-flight
2.5.2.1 Launch Phase Staffing
2.5.2.2 In-flight Phase Staffing
2.5.2.3 Landing Phase Staffing
2.5.2.3.1 Recumbent Seats (if required)
2.5.3 Post-flight
2.5.3.1 Emergency Medical Services
2.5.3.1.1 General
2.5.3.1.2 Emergency Medical Services Plan

3.0 Training Section
3.1 Astronaut Training
3.1.1 Crewmember Medical Training
3.1.2 Crew Medical Officer (CMO) Training
3.2 Crew Surgeon Training
3.2.1 Medical Operations Flight Surgeon Controller Training
3.2.2 Emergency Medical Services
3.3 Other Support Personnel Training
3.3.1 Medical Operations Flight Controller Training
3.3.2 Emergency Medical Services

Appendix A Acronyms
Appendix B Reference Documents

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APPENDIX D
Rationale for Levels of Care

D.1 Standard of Care and Level of Care

Medicine uses two phrases to describe care: (1) the Level of Care that one can provide and (2) the Standards of Care. These are not interchangeable terms. "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.2 Level of Care Zero

Rationale — The expectations of need for medical care is low (for example, 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.3 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.

D.4 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

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support contingency emergencies such as anaphylaxis or toxic exposure, and routine diagnoses such as urinary retention, space motion sickness, ocular foreign bodies, etc. The relatively short mission duration eliminates the need for medical hardware to evaluate long-term changes due to microgravity. For example, ultrasound, Holter monitoring, and surgical capability are not necessary components of this medical suite.

D.5 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.6 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 (PCA) may be carried. Although immediate life-saving measures are still to be available, such as an Automated External Debrillator (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.7 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, Shuttle, CEV, or other vehicle).

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D.8 Level of Care Five

Rationale — The training and caliber of the care giver is at the physician level, due to 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 care giver, 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 Definitions

E.1.1 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.1.2 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.1.3 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.2 Implementation Strategies

E.2.1 Primary Strategies

Primary prevention during astronaut selection is implemented by the Space Medicine 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.2.2 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 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.

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E.2.3 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 Medicine Division at JSC through Medical Operations. This includes, but is not limited to, providing an ACLS/ATLS-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.2.4 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 document. Medical support at all primary landing sites are 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 Fitness-for-Duty Aerobic Capacity Standard

Human space flight and the consequent exposure to microgravity result in a well-documented reduction of aerobic capacity (VO_{2max}). In the experience of the international space community, including the United States and Russian space programs, aerobic capacity degrades 15-30 percent during initial exposure to microgravity (1-3 weeks), often followed by an in-flight training effect. Testing has revealed that aerobic capacity is decreased again upon return to the 1g environment. The current countermeasure strategy, both for the microgravity environment and for reconditioning upon return, is cardiovascular exercise.

Studies have shown that individuals with significantly reduced aerobic capacity have difficulty performing or are unable to perform specific job-related tasks such as load carrying and emergency egress. The inability of an individual to perform assigned tasks can lead to dependence on other crewmembers. Fit crewmembers may have to compensate for the individual with compromised capabilities and have the added responsibility of caring for the impaired crewmember, which may further compromise mission objectives.

In-flight decreases in aerobic capacity may result from variable causes such as physiological adaptation to microgravity (this is especially true in the first 4 weeks of space flight), problems with the functioning of exercise equipment, decreased intensity and/or duration of exercise, and inaccurate/unreliable VO_{2max} measurement capabilities in-flight. In order to assess the risk adequately, VO_{2max} measurements, either actual or derived, may be 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.

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F.2 Fitness-for-Duty Sensorimotor Standard

During space flight missions, sensorimotor impairments may occur. 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 prior to 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 four 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 four 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. Gaze Control Performance can be broken down as follows: gaze battery test score (value greater than 10th percentile relative to baseline score); gaze battery test score (value less than 10th

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percentile but greater than 5th percentile relative to baseline score); and gaze battery test score (value less than 5th percentile relative to baseline score).

The most common sensorimotor difficulties encountered in space flight are space motion sickness (SMS) and post-flight neurovestibular symptoms. SMS is routinely controlled with pharmacological countermeasures. 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.3 Fitness for Duty Behavioral Health and Cognition Standard

Factors that impact behavioral health and cognition during space flight include microgravity, isolation and confinement, radiation, workload, sleep and circadian rhythm disturbances, and psychological adaptation. In the experience of the international space community, including United States and Russian space programs, behavioral health issues have resulted in early termination of missions, depressive states, degraded performance, and interpersonal friction. Efforts to mitigate loss of behavioral health have included pharmacologic and physical countermeasures and training.

Behavioral health encompasses behavior, mood, cognition, sleep-circadian cycles, work-rest, and psychological adaptations that suppress disease or disorders and sustain safe and effective performance.

The development of baselines established from behavioral health and cognitive assessment tools are critical to the development of operating (performance) and morbidity (medical) ranges. Fitness for duty examinations may employ behavioral health and cognitive assessment tools during exploration missions to measure the crewmember's capability and ability to operate and perform in the nominal ranges.

An individual Earth baseline may be developed for each astronaut and then monthly monitoring testing maintained. In case of a clinical insult (head trauma, decompression sickness involving the central nervous system, exposure to toxins, cognitive side effects to medication, etc.), then additional testing can be obtained to assist with medical treatment and disposition.

It may be necessary to carry out a task-specific performance readiness assessment before a critical task (e.g., docking, EVA, robotic arm operations) is begun on long-duration missions. The performance on an assessment determines the readiness of the individual to initiate that task. These performance ranges require re-evaluation and update.

The normal uninterrupted sleep period for humans is 7-8 hours. An Earth sleep baseline may be obtained for each individual astronaut. An individual confidence level is developed for each individual astronaut for sleep-related fatigue. These clinical ranges require regular re-evaluation and update.

The Circadian Clinical Range is maintained as the individual astronaut or crew maintains a 24-hour cycle set to one time zone. When an individual or crew cycle is shifted $\geq$ 2 hours for 4 or more days, then adaptation has to occur at the rate of 1 day per hour. Shifting causes changes in physiology and directly affects sleep, physiological fatigue, and performance. The clinical range requires continued re-evaluation and update.

The planned nominal number of work hours is 6.5 hours per day. It is recommended not to exceed a 48-hour total workweek. Maintaining the nominal work hours and workload is even more important during critical operations. A critical overload workload is defined as 10-hour

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work days > 3 days in a week or > 60 hours in a workweek. This performance range requires continued re-evaluation and update.

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F.4 Fitness-for-Duty Hematology and Immunology Standard

During space flight, immune system changes occur which 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 that level which 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 prior to 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 which are associated with specific clinical morbidities.

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F.5 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) due to inadequate supply, inadequate stability, or increased metabolism and excretion can lead to illness and/or performance decrements. Nutritional status has to be adequate prior to 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.

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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.6 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, POL, 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 POL 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.

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Knowledge gaps have been identified to define the current rationale for not having definitive standards for missions, tasks, vehicles, and suits not yet characterized. Table 2 below is the initial assessment but requires quantitative measures by task.

Table 2— CEV Functional Strength Requirements

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.7 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 bone mineral density (BMD) as a T-score > -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.

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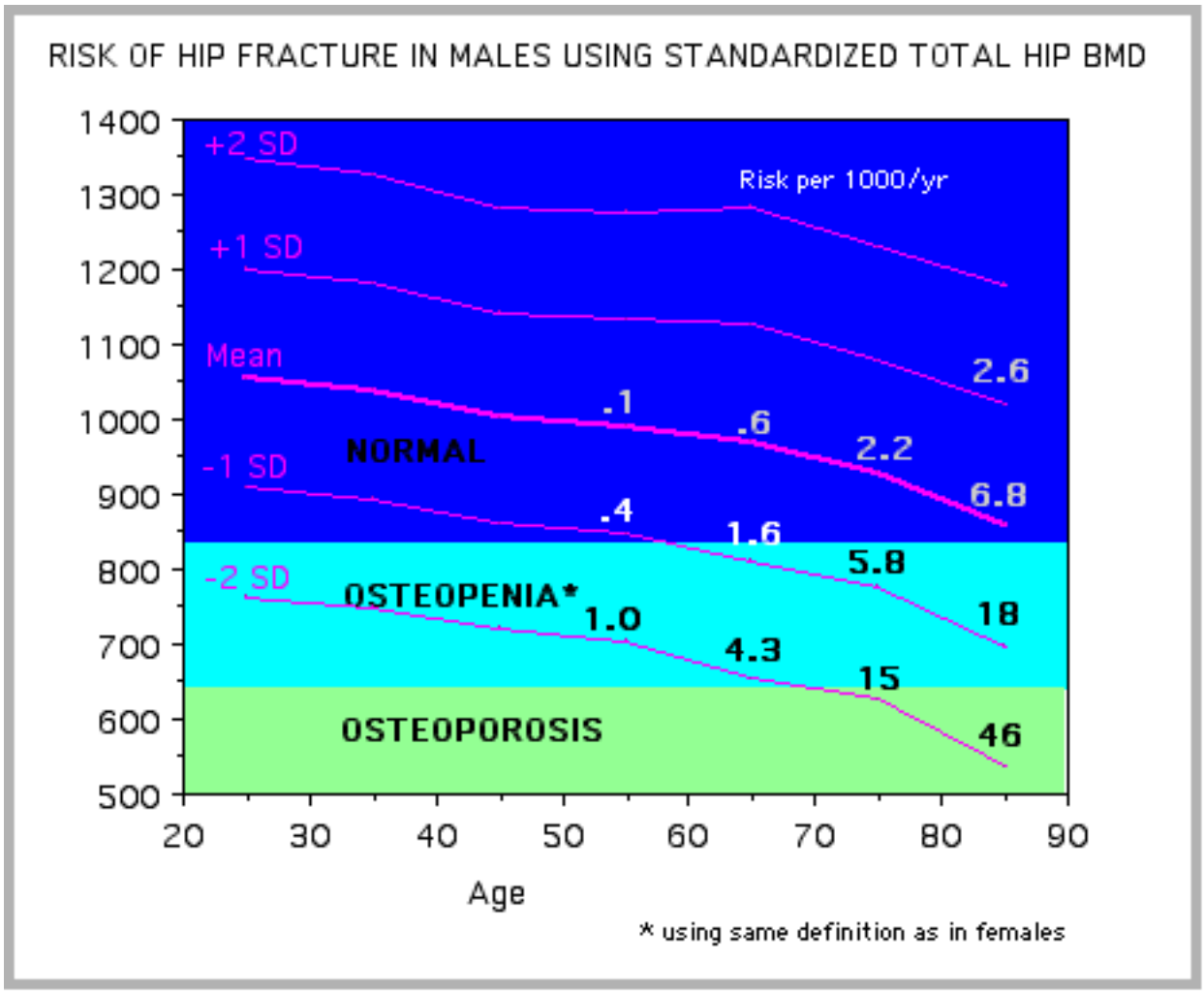

Figure 1—Risk of Hip Fracture in Males Using Standardized Total Hip BMD

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.8 Space-Permissible Exposure Limit (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 change 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 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 and a reasonable "worst-case" space environment to be encountered on specific missions. Uncertainties are due 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.

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F.8.1 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.8.2 Career Cancer Risk Limits

Career exposure to radiation is limited to not exceed 3 percent REID for fatal cancer. NASA assures that this risk limit is not exceeded at a 95 percent confidence level using a statistical assessment of the uncertainties in the risk projection calculations to limit the cumulative effective dose (in units of Sievert) received by an astronaut throughout his or her career.

F.8.3 Cancer Risk-to-Dose Relationship

The relationship between radiation exposure and risk is age and sex specific due to latency effects and differences in tissue types, sensitivities, and life-spans between sexes. Table 3 lists examples of career effective dose (E) limits for a REID = 3 percent for missions of 1-year duration or less. Limits for other career or mission lengths vary and can be calculated using the appropriate life-table formalism. Tissue contributions to effective doses are defined in table 3. Estimates of average life-loss based on low linear-energy transfer (LET) radiation are also listed in table 3; however, higher values may be expected for high LET exposures such as GCR.

F.8.4 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 central nervous system are imposed to limit or prevent risks of degenerative tissue diseases (e.g., stroke, coronary heart disease, striatum aging, etc.). 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 lifeloss from gamma-ray-induced heart disease death is approximately 9 years. Dose limits for non-cancer effects (units of milli-Gray Equivalent (mGy-Eq)) are listed in table 4.

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Table 3—Example Career Effective Dose Limits in Units of Sievert (mSv) For 1-year Missions and Average Life-loss for an Exposure-induced Death for Rradiation Carcinogenesis (1 mSv= 0.1 rem)

	E(mSv) for 3% REID (Ave. Life Loss per Death, yr)	
Age, yr	Males	Females
25	**520 (15.7)**	**370 (15.9)**
30	**620 (15.4)**	**470 (15.7)**
35	**720 (15.0)**	**550 (15.3)**
40	**800 (14.2)**	**620 (14.7)**
45	**950 (13.5)**	**750 (14.0)**
50	**1150 (12.5)**	**920 (13.2)**
55	**1470 (11.5)**	**1120 (12.2)**

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Table 4—Dose limits for short-term or career non-cancer effects (in mGy-Eq. or mGy) Note RBE's for specific risks are distinct as described below.

Organ	*30 day limit*	*1 Year Limit*	*Career*
Lens*	**1000 mGy-Eq**	**2000 mGy-Eq**	**4000 mGy-Eq**
Skin	**1500**	**3000**	**4000**
BFO	**250**	**500**	**Not applicable**
Heart**	**250**	**500**	**1000**
CNS***	**500**	**1000**	**1500**
CNS* (Z≥10)**	**-**	**100 mGy**	**250 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.

**Heart doses calculated as average over heart muscle and adjacent arteries.

***CNS limits should be calculated at the hippocampus.

F.8.5 The Principle of As Low as Reasonably Achievable (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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