	METRIC/SI (ENGLISH)
NASA TECHNICAL STANDARD **National Aeronautics and Space Administration**	**NASA-STD-3001, VOLUME 2, REVISION C**
	Approved: 2022-04-08 **Superseding NASA-STD-3001, Volume 2, Revision B**

NASA SPACE FLIGHT HUMAN-SYSTEM STANDARD

VOLUME 2: HUMAN FACTORS, HABITABILITY, AND ENVIRONMENTAL HEALTH

DOCUMENT HISTORY LOG

Status	Document Revision	Change Number	Approval Date	Description
Baseline			2011-01-10	Initial Release
Revision	A		2015-02-10	Revision of lunar dust requirement, section 6.4.4.2
Revision	B		2019-09-09	Editorial changes throughout document with addition of the following sections/requirements: 3.5/[V2 3006], 5.2.4/[V2 5008], 6.3.1.3/[V2 6105], 6.6.1.14/[V2 6106], 7.3.2.5/[V2 7085], 8.7.4/[V2 8059], 8.7.5/[V2 8060], 11.1.3.2/[V2 11028], 11.2.3.1/[V2 11029], 11.2.3.2/[V2 11030], 11.2.5.1/[V2 11031], 11.3/[V2 11032], 11.4/[V2 11033], 11.5/[V2 11034], 11.6/[V2 11035], 11.7/[V2 11036], 11.8/[V2 11037], 11.9/[V2 11038], 11.10/[V2 11039], and all of Section 13. Deletion of the following sections/requirements: 3.1/[V2 3001], 3.2/[V2 3002], 3.3/[V2 3003], 3.4/[V2 3004], 3.5/[V2 3005], 6.2.1.4/[V2 6005], 6.2.5.2/[V2 6018], 6.3.1.3/[V2 6028], 6.6.1.1/[V2 6071], 6.6.1.2/[V2 6072], 6.6.2.14/[V2 6086], 7.9.3/[V2 7072], 7.10.5/[V2 7078], 8.1.4/[V2 8004], 8.6.1.2/[V2 8044], 8.6.1.5/[V2 8047], 8.6.1.6/[V2 8048], 8.7.4/[V2 8054], 10.2.1.1/[V2 10029], 10.3.2.4/[V2 10041], 10.3.4.1.1/[V2 10051], 10.5.3.8/[V2 10092], 11.1.2.3/[V2 1004], 11.1.3.3/[V2 11008], 11.2.3.1/[V2 11026] and Section 12. The following sections/requirements were materially changed either in the text of this NASA Technical Standard and/or in the rationale:

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Revision	B		2019-09-09	Continued: 1.1, 1.2, 1.3, 1.4, 4.2.2/[V2 4006], 4.4/[V2 4008], 4.8.3/[V2 4014], 5.1.1/[V2 5001], 5.1.2/[V2 5002], 5.1.3/[V2 5003], 5.2.1/[V2 5005], 5.2.2/[V2 5006], 5.2.3/[V2 5007], 6.2.1.2/[V2 6003], 6.2.1.3/[V2 6004], 6.2.2.1/[V2 6006], 6.2.2.2/[V2 6007], 6.2.2.3/[V2 6008], 6.2.3.2/[V2 6011], 6.2.4.1/[V2 6012], 6.2.4.3/[V2 6014], 6.2.5.1/[V2 6017], 6.2.6.1/[V2 6020], 6.2.6.2/[V2 6021], 6.2.7.1/[V2 6022], 6.3.1.1/[V2 6026], 6.3.2.7/[V2 6035], 6.4.4.1/[V2 6052], 6.4.5.3/[V2 6056], 6.4.5.4/[V2 6057], 6.4.8/[V2 6063], 6.5.1/[V2 6064] (Figures 4 and 5), 6.5.2.2/[V2 6066], 6.5.2.3/[V2 6067], 10.6.1.9/[V2 10108], 11.1.2.1/[V2 11006], 11.1.2.2/[V2 11007], 11.1.3.3/[V2 11014], 11.1.6/[V2 11023], 11.2.1.1/[V2 11024], 11.2.2.1/[V2 11025], 11.2.4.1/[V2 11027],
Revision	C		2022-04-08	Editorial changes throughout document with the following sections/requirements that were materially changed either in the text of this NASA Technical Standard and/or in the rationale: 1.1, 1.2, 1.3, 2.1.2, 2.2, 2.3, 3.1, 3.2; 3.2.1/[V2 3006], 4.2/[V2 4013], 4.3/[V2 4015], 5, 5.1.1/[V2 5001], 5.1.2/[V2 5002], 5.1.3/[V2 5003], 5.1.4/[V2 5004], 5.2, 5.2.1/[V2 5005], 5.2.2/[V2 5006], 5.2.3/[V2 5007], 5.2.4/[V2 5008] 6.1/[V2 6001], 6.2, 6.2.1.1/[V2 6002], 6.2.1.2/[V2 6003] and Table 1, 6.2.1.3/[V2 6004], 6.2.2.1/[V2 6006], 6.2.2.2/[V2 6007], 6.2.2.4/[V2 6008], 6.2.3/[V2 6011] and Table 2, 6.2.4.1/[V2 6012] and Figure 2, 6.2.4.2/[V2 6013], 6.2.5/[V2 6017], 6.2.6.1/[V2 6020], 6.2.6.2/[V2 6021], 6.2.7.1/[V2 6022], 6.2.7.2/[V2 6023], 6.2.7.3/[V2 6024], 6.2.7.4/[V2 6025], 6.2.8.1/[V2 6107], 6.2.8.2/[V2 6108], 6.3.1.1/[V2 6026], 6.3.1.4/[V2 6046] and Table 3, 6.3.4.1/[V2

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				6.3.1.2/[V2 6027] and Table 3, 6.3.1.3/[V2 6105], 6.3.2.1/[V2 6029], 6.3.2.2/[V2 6030], 6.3.2.3/[V2 6031], 6.3.2.4/[V2 6032], 6.3.2.5/[V2 6033], 6.3.2.6/[V2 6034], 6.3.2.7/[V2 6035], 6.3.2.8/[V2 6036], 6.3.2.9/[V2 6037], 6.3.2.10/[V2 6038], 6.3.4.1/[V2 6041], 6.3.4.2/[V2 6042], 6.3.4.3/[V2 6043], 6.3.4.4/[V2 6044], 6.3.4.5/[V2 6045], 6.4.5.1/[V2 6054], 6.4.5.2/[V2 6055], 6.4.5.3/[V2 6056], 6.4.5.4/[V2 6057], 6.5.3.1/[V2 6068], 6.8.1.2/[V2 6096], 7.1.1.5/[V2 7005] and Table 12, 7.1.1.6/[V2 7006] and Table 13, 7.1.2.6/[V2 7013], 7.2.3/[V2 7018], 7.3.1.9/[V2 7028], 7.3.2, 7.3.2.1/[V2 7030], 7.3.2.2/[V2 7031], 7.3.2.3/[V2 7032], 7.3.2.4/[V2 7033], 7.3.2.6/[V2 7034], 7.3.2.8/[V2 7036], 7.3.2.9/[V2 7037], 7.4.2/[V2 7039], 7.5.1/Table 17, 7.5.2/[V2 7044], 7.5.4/[V2 7047], 7.5.5/[V2 7048], 7.8.2/[V2 7067], 7.8.3/[V2 7068], 7.10.4/[V2 7077], 8.1.2/[V2 8002], 8.1.3/[V2 8003], 8.2.2.2/[V2 8008], 8.2.2.3/[V2 8009], 8.2.3/[V2 8012], 8.3.3/[V2 8015], 8.3.4/[V2 8016], 8.3.5/[V2 8017], 8.3.6/[V2 8018], 8.3.7/[V2 8019], 8.3.9/[V2 8021], 8.3.10/[V2 11002], 8.4.1.5/[V2 8026], 8.5.2/[V2 8034], 8.5.3/[V2 8035], 8.5.4/[V2 8036], 8.5.5/[V2 8037], 8.5.7/[V2 8039], 8.5.11/[V2 11003], 8.5.12/[V2 11012], 8.6.1.3/[V2 8046], 9.3.1.10/[V2 9014], 9.3.1.11/[V2 9015], 9.7.2.2/[V2 9040], 9.7.2.3/[V2 9041], 9.7.3.5/[V2 9049], 10.1.6.3/[V2 10019], 10.3.4.2.4/[V2 10059], 10.6.1.4/[V2 10103], 10.6.1.8/[V2 10107], 10.6.1.12/[V2 10111] The following sections/requirements were added throughout this NASA Technical Standard: 3.1.1, 3.2.2/[V2 3102], 3.2.3/[V2 3101], 4.1.1/[V2 4102], 4.1.2/[V2 4103], 4.1.3. 4.1.3.1/[V2 4103], 4.1.3.2/[V2 4104], 6.2.2.3/[V2 6150], 6.2.4.2/Figure 3, 6.2.4.3/[V2 6151], 6.2.4.4/[V2 6152], 6.2.7.3/Table 3, 6.2.7.5/[V2 6153], 6.2.8.1/[V2 6107], 6.2.8.2/[V2 6108], 6.3.2/[V2 6109], 6.3.3/[V2

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FOREWORD

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

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

This NASA Technical Standard establishes Agency-wide requirements that minimize health and performance risks for flight crew in human space flight programs. This NASA Technical Standard applies to space vehicles, habitats, suits (extravehicular activity [EVA] and intravehicular activity [IVA]/launch, entry and abort [LEA]), facilities, payloads, and related equipment with which the crew interfaces during space flight and lunar and planetary, e.g., Mars, habitation.

Requests for information should be submitted via “Feedback” at https://standards.nasa.gov. Requests for changes to this NASA Technical Standard should be submitted via Marshall Space Flight Center (MSFC) Form 4657, Change Request for a NASA Engineering Standard.

04/08/2022

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NASA Chief Health and Medical Officer
NASA Headquarters

Approval Date

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NASA SPACEFLIGHT HUMAN-SYSTEM STANDARD

VOLUME 2: HUMAN FACTORS, HABITABILITY, AND ENVIRONMENTAL HEALTH

1. SCOPE

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

1.1 Purpose

The purpose of this NASA Technical Standard is to provide uniform technical requirements for the design, selection, and application of hardware, software, processes, procedures, practices, and methods for human-rated systems.

NASA-STD-3001, Space Flight Human-System Standard, is a two-volume set of NASA Agency-level requirements established by the Office of the Chief Health and Medical Officer (OCHMO), directed at minimizing health and performance, safety, and engineering risks for flight crews in human space flight programs. Volume 1 of NASA-STD-3001, Crew Health, sets requirements for fitness for duty, space flight permissible exposure limits, permissible outcome limits, health and medical care requirements, medical diagnosis, intervention, treatment and care, and countermeasures. Volume 2 of NASA-STD-3001, Human Factors, Habitability, and Environmental Health, focuses on human physical and cognitive capabilities and limitations and defines requirements for spacecraft (including orbiters, habitats, and suits), internal environments, ground processing, facilities, payloads, and related equipment, hardware, and software systems.

Volume 1 of NASA-STD-3001 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. In Volume 2, the focus turns to human-system integration where the context is about how the human crew interacts with designed systems and the environment. The focus is on performance issues during a mission—whether the human and the designed system can function together (within the environment) and accomplish the tasks necessary for mission success.

Volume 2 of NASA-STD-3001 is applicable to all human space systems. Developers of a system are to write design requirements tailored for their system that will ensure the end product meets the requirements of Volume 2. It should be noted that while this document covers all phases of flight, tailoring must take into consideration a lack of emphasis on partial gravity operations and spacecraft that will be used in both microgravity and partial gravity. This may include adjustments to existing requirements as well as inclusion of additional requirements to encompass the same intent as the content of this document. A supplementary NASA document, NASA/SP-2010-3407, Human Integration Design Handbook (HIDH), can help with the preparation of the system-specific design requirements. The HIDH is a compendium of human space flight history and knowledge. It is organized in the same sequence as NASA-STD-3001, Volume 2, and provides useful background information and research findings. While the HIDH is not a NASA Technical Standard or a requirement, it should be a resource to understand the background associated with the standards to prepare the program- or project-specific requirements. The HIDH can be used not only in the preparation of requirements but also as a useful tool for designers. A complementary reference document to the HIDH is NASA/TP-2014-218556, Human Integration Design Processes (HIDP). The HIDP describes the “how-to” processes, including methodologies and best practices that NASA has used during the development of crewed space systems and operations.

This NASA Technical Standard addresses the equipment and operational interfaces for both flight crew and ground personnel. System requirements fall into one of two categories:

- Requirements for the design of systems that directly interface with the flight crew (and only the flight crew) during a mission are in sections 3 through 11. These requirements include such topics as environmental support systems, architecture, controls and displays, and operations.

- Requirements for the design of systems that ground support personnel and/or flight crews access during assembly, test, checkout, or troubleshooting procedures supporting ground processing, launch, landing, and recovery operations, including simulations for training and/or ground operations development/refinement purposes are addressed in section 12. Section 12 ensures that ground personnel capabilities are accommodated during ground processing and that the flight hardware will not be damaged during ground operations. Requirements for these systems consider the unique characteristics, capabilities, and needs of both the flight crew and ground support personnel.

This NASA Technical Standard contains fundamental, NASA-sanctioned information necessary for building and verifying human-rated spacecraft and is to be used for the development of lower level, program/project-specific requirements.

1.2 Applicability

This NASA Technical Standard is applicable to programs and projects that are required to obtain a human-rating certification. NPR 8705.2, Human-Rating Requirements for Space Systems, defines the requirements for space systems. HEOMD-003, Crewed Deep Space Systems Human Rating Requirements and Standards is a tailoring of NPR 8705.2 for crewed deep space systems. The intent of this NASA Technical Standard is to be the foundation for the program/project requirements and verification documentation.

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

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

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

Verifiable requirement statements are designated by the acronym “V2” (Volume 2), numbered, and indicated by the word “**shall.**” Explanatory or guidance text is indicated in italics beginning in section 3. To facilitate requirements selection and verification by NASA programs and projects, a Requirements Compliance Matrix is provided in Appendix D, Table 38.

1.3 Tailoring

As per NPR 7120.5, NASA Space Flight Program and Project Management Requirements, tailoring is the process used to adjust or seek relief from a prescribed requirement to accommodate the needs of a specific task or activity (e.g., program or project). Tailoring is both an expected and accepted part of establishing proper requirements. The tailoring of the requirements and associated waivers and deviations from this NASA Technical Standard for application to a specific program or project **shall** be formally documented as part of program or project requirements and require formal approval from the HMTA/OCHMO in accordance with NPR 7120.5.

1.4 Authority

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

2. APPLICABLE DOCUMENTS

2.1 General

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

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

2.1.2 Non-use of a specifically designated version is approved by the delegated Technical Authority.

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

2.2 Government Documents

NASA

49 CFR Part II, Parts 213 and 238	Department of Transportation, Federal Railway Administration: Vehicle/Track Interaction Safety Standards; High-Speed and High Cant Deficiency Operations; Final Rule March 13, 2013
NPR 7120.5	NASA Space Flight Program and Project Management Requirements
NASA-STD-3001, Volume 1	NASA Space Flight Human-System Standard, Volume 1: Crew Health
NASA/SP-20210010952	NASA Human Systems Integration Handbook https://ntrs.nasa.gov/citations/20210010952
NASA/TM-2013-217380	Application of the Brinkley Dynamic Response Criterion to Spacecraft Transient Dynamic Events
JPR-1880.4	Requirements and Limitations for Exposure to Reduced Atmospheric Pressure
JPR-1800.5	Biosafety Review Board Operations and Requirements
JSC-20584	Spacecraft Maximum Allowable Concentrations for Airborne Contaminants

JSC-26895	Guidelines for Assessing the Toxic Hazard of Spacecraft Chemicals and Test Materials (https://www.nasa.gov/sites/default/files/atoms/files/jsc_26895_rev1_final.pdf)
JSC-33124	41-Node Transient Metabolic Man Computer Program Documentation – A thermal regulatory model of the human body with environment suit applications
NPD 8020.7	Biological Contamination Control for Outbound and Inbound Planetary Spacecraft (https://nodis3.gsfc.nasa.gov/npg_img/N_PD_8020_007G_/N_PD_8020_007G__main.pdf)

2.3 Non-Government Documents

American Conference of Governmental Industrial Hygienists (ACGIH)

ACGIH	Threshold Limit Values (TLVs®) and Biological Exposure Indices (BEIs®) Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices (www.acgih.org/)

American National Standards Institute (ANSI)

ANSI C78-377 (see NEMA C78.377)	Electric Lamps - Specifications for the Chromaticity of Solid State Lighting (SSL) Products
ANSI/ASA S2.70 (2006)	Guide for the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hand
ANSI/ASA S3.2 (2009) (see LIA Z136.1)	Method for Measuring the Intelligibility of Speech over Communications Systems
ANSI LIA Z136.1 (2014)	American National Standard for Safe Use of Lasers

ASTM International

ASTM C1057-17	Standard Practice for Determination of Skin Contact Temperature
ASTM F2291-20	Standard Practice for Design of Amusement Rides and Devices

Illuminating Engineering Society (IES)

IES TM-30	Method for Evaluating Light Source Color Rendition

Institute of Electrical and Electronics Engineers (IEEE)

IEEE C95.1™	IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz

International Electrotechnical Commission (IEC)

IEC/TR 60479	Effects of current on human beings and livestock
IEC 60601	Medical Electrical Equipment

International Organization for Standardization (ISO)

ISO 2631-1:1997	Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration – Part 1: General requirements, Annex B and Annex D
ISO 20283-5	Mechanical vibration—Measurement of vibration on ships; Part 5 - Guidelines for measurement, evaluation and reporting of vibration with regard to habitability on passenger and merchant ships
ISO 7731:2003(E)	Ergonomics -- Danger signals for public and work areas -- Auditory danger signals

Reference documents are provided in Appendix A.

2.4 Order of Precedence

2.4.1 The requirements and standard practices established in this NASA Technical Standard do not supersede or waive existing requirements and standard practices found in other Agency documentation.

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

Note: ACRONYMS, ABBREVIATIONS, and SYMBOLS are provided in Appendix B.

Note: DEFINITIONS are provided in Appendix C.

3. PROGRAM/PROJECT IMPLEMENTATION STANDARDS

Methods for incorporating an understanding of human capabilities, limitations, and functions (including ill, injured, and deconditioned states) are to be described in an implementation process resulting in performance standards. This strategy ensures that human performance is consistently addressed with system performance throughout the system life cycle and that the design is informed and enhanced by evaluations of human performance-related risks and considers human integration at all levels of the system, from individual components to the level of the complete integrated system.

3.1 Applicability of this NASA Technical Standard

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

- *a. Gravitational Environment,*
- *b. Full Mission Duration (see section 3.1.1),*
- *c. Time to receive terrestrial medical capability,*
- *d. Radiation Environment,*
- *e. Spacesuit Capability (see Appendix E, spacesuit),*
- *f. Destination,*
- *g. Mission Phase, or*
- *h. Other definable mission parameter.*

As per NPR 7120.5, during the systems requirements phase of program or project development, the appropriate requirements will be deemed applicable based on the program mission parameters. Refer to Figure 1, Applicability, Tailoring, and Verification of Requirements for Human Space Flight Programs/Projects, for the process of applicability, tailoring, and verification of requirements for programs or projects.

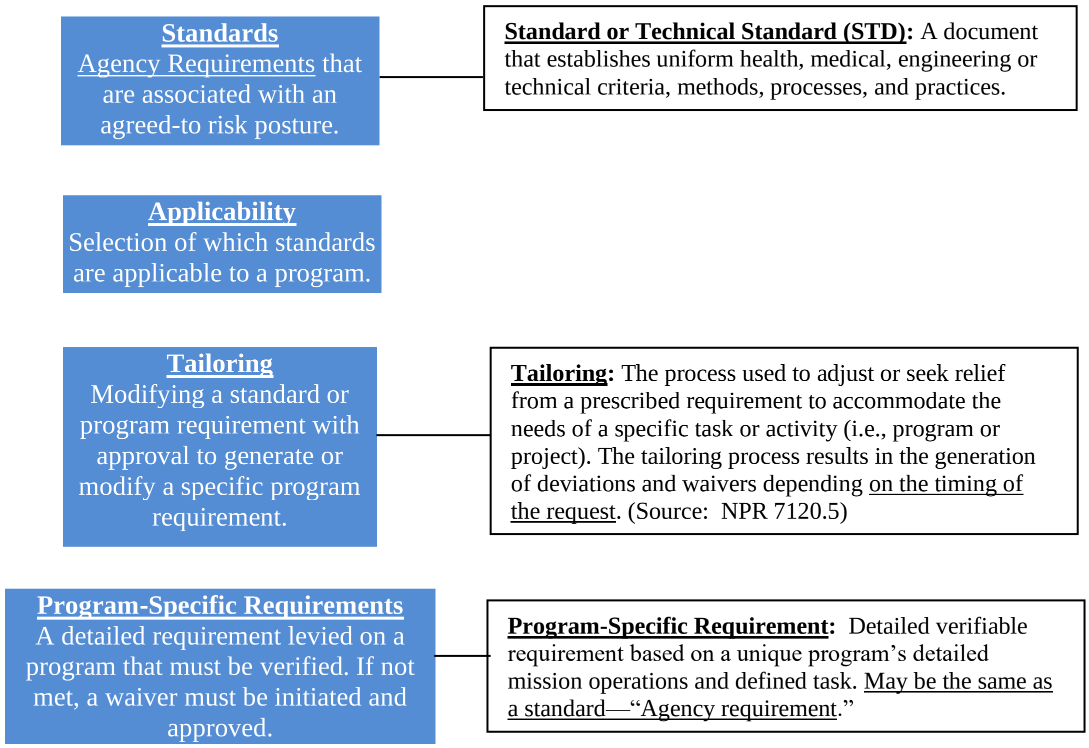

Figure 1—Applicability, Tailoring, and Verification of Requirements for Human Space Flight Programs/Projects

3.1.1 Full Mission Duration Applicability

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

Missions may be comprised of consecutive segments that occur in different vehicles, take place in different locations in space with varying distances from Earth, and last for different durations. Many requirements that pertain to cumulative exposures and conditions (such as Permissible Exposure Limits) have been tailored (relaxed) to accommodate short missions occurring in single vehicles. However, for multi-segment or multi-vehicle missions, cumulative exposure over the entire duration of the mission needs to be considered. Exposure in one vehicle that is occupied for a segment of the full mission duration cannot be taken in isolation of the rest of the mission. It is not advisable for each vehicle to maintain its own short duration exposure requirements and expect other vehicles or habitats in the mission to lower their exposure limits to compensate for a higher exposure level in another vehicle. Similarly, a vehicle cannot expect other vehicles within the enterprise to compensate for lack of countermeasures in that vehicle.

3.2 Systems Engineering Processes and Requirements

This NASA Technical Standard is tightly linked with NPR 7123.1, NASA Systems Engineering Processes and Requirements, and NPR 8705.2. NPR 7123.1 requires a human-centered design (HCD) process along with a Human Systems Integration Plan (HSIP). The HCD process is characterized by task analysis, prototyping, early user involvement, and iterative, developmental human-in-the-loop (HITL) testing. The HSIP includes guidance for integrating the implementation of integration of human considerations into the system acquisition and development processes to enhance human system design, reduce life-cycle ownership cost, and optimize total system performance. NASA HSI domains include human factors engineering, operations, safety, training, maintainability and supportability, and habitability and environment. These six NASA HSI domains are considered concurrently and integrated with all other systems engineering design activities. NPR 8705.2 requires the program/project to establish a human-systems integration team to support the implementation of the HSIP. NASA-STD-3001 extends human-centric design and HSI as outlined in NPR 7123.1 and NPR 8705.2.

3.2.1 Human-Centered Task Analysis

[V2 3006] Each human space flight program or project **shall** perform a human-centered task analysis to support systems and operations design.

[Rationale: A task analysis is a methodical and iterative process that analyzes tasks allocated to the human by decomposing individual tasks into simpler actions (task steps) and identifying the task parameters and conditions that can either enable or constrain human interface interactions, including identification of information required to perform the task. The focus of the task analysis is on the human and how they interact, both physically and mentally, with the hardware, software, procedures, and other users of the system to perform the tasks. It spans all mission phases and includes nominal, maintenance, contingency, and emergency operations. A task analysis may be performed for any human interaction with the system and is not restricted to flight crew.

The task analysis can be initiated as early as the Concept and Technology Development phase, when baseline mission concepts, requirements, technologies, and the human role are being defined. As design concepts are iteratively evaluated and matured, task definitions are refined. By the critical design phase, the task analysis should be a mature product. A task analysis can continue to be iteratively updated after the critical design phase and even after certification to reflect changes in design or operational use between missions. Task analysis can be used in the development or identification of gaps in requirements. The analysis is used to drive design, developmental HITL evaluation, and verification efforts for task effectiveness, efficiency, satisfaction and safety. It also informs the development of human error analysis, operational procedures, and training. Task analysis is critical to the implementation and verification of numerous other standards. For more information, see 4.1 in the HIDP.

Task analysis will be updated and delivered throughout the development lifecycle as contractual data requirements in Statements of Work, Data Requirements Documents (DRDs), Data Procurement Documents (DPDs), and/or relevant Verification Closure Notices (VCNs).]

3.2.2 Human Error Analysis

[V2 3102] Each human space flight program or project **shall** perform a task-based human error analysis (HEA) to support systems and operations design.

[Rationale: HEA is a systematic approach to evaluate human actions and identify potential human error, consequences, and mitigations. Potential human errors include inadvertent operator actions, failure to perform an action, performing a wrong action, performing an action incorrectly, and performing an action with incorrect timing. The intent of the HEA is to identify human error and apply the appropriate error management to mitigate its effect on the system by designing the system according to the following precedence: (1) prevent the error, (2) reduce the likelihood of the error and provide the capability for detection in time to correct and recover, and (3) limit the negative effects of the error.

HEA spans all mission phases and includes nominal, contingency, and emergency operations, including ground operations when crew is present. It includes interactions with hardware, software, procedures, and other users of the system. Since the number of tasks associated with a system's operation and maintenance can be immense, the HEA should focus on those tasks, as defined by task analysis and safety hazard analyses, that are most important to mission success, starting with those that could result in catastrophic failure.

The HEA is used to identify and mitigate error traps in design and assist in scoping the selection of task sequences and scenarios for HITL verification testing. The HEA will be updated and delivered throughout the development lifecycle as contractual data requirements in either Statements of Work, Data Requirements Documents (DRDs), Data Procurement Documents (DPDs) and/or Verification Closure Notices (VCNs). A summary of the human error analysis performed and how the results influenced the system design is required to be included in the Human Error Analysis Summary Report in the Human Rating Certification Package at each lifecycle milestone design review.]

3.2.3 Iterative Developmental Testing

[V2 3101] Each human space flight program or project **shall** perform iterative HITL testing throughout the design and development cycle.

[Rationale: As a key component of the HCD process as defined in Human Integration Design Process (NASA/TP-2014-218556) and the HSI process as defined by the NASA Human Systems Integration Handbook (NASA/SP-20210010952), iterative testing is an important method for identifying issues early, when changes are affordable and feasible. It is a structured way to mature the design and to track readiness for verification. Iterative HITL testing is required throughout the design and development cycle to identify issues related to usability, operability,

workload, situation awareness, display design, and commonality. Test report products and evidence of the influence of outcome on design are to be delivered throughout the development lifecycle as contractual data requirements in the Statement of Work, Program and Design Milestone entry and exit criteria, or Data Procurement Documents.]

4. PHYSICAL CHARACTERISTICS AND CAPABILITIES

A systems engineering process that adequately considers human performance variability and limitations during spacecraft design, development, testing, and evaluation is of critical importance to the health, safety, and performance of flight crews, as well as to the protection of hardware and systems. As with any other system component, there are limits to human capabilities. The conditions encountered during space flight can degrade human capabilities. These performance-limiting conditions may include environmental factors such as weightlessness and g-transitions, physiological effects such as space sickness and spatial disorientation, and other factors such as confinement and protective clothing.

The human performance envelope is bounded by physical as well as cognitive limitations. Accommodating these limitations during space flight is critical to all aspects of mission success, including the maintenance of crew health and safety.

Physical characteristics and capabilities include body dimensions, range of motion, mass, volume, surface area, and strength. It is important that the design of equipment, including vehicles, spacesuits, and other interfaces, accommodates the physical characteristics of the entire user population. Adjustments for the effects of external factors such as gravity environments, clothing, pressurization, and deconditioning related to mission duration are to be included in the design.

A system designed for human use or habitation must accommodate the range of human characteristics and capabilities relevant to the system and operating environment for the NASA-defined crew population. Datasets are provided that include characteristics and capabilities for anthropometric dimensions, range of motion, strength, mass, volume, and surface area. The datasets and their supplemental information in Appendix F, Physical Characteristics and Capabilities, take into account human characteristics such as age, sex, and physical condition as well as mission characteristics such as clothing and suit pressurization.

4.1 Physical Data Sets

4.1.1 Functional Anthropometric Accommodation

[V2 4102] The system **shall** ensure the range of potential crewmembers can fit, reach, view, and operate the human systems interfaces by accommodating crewmembers with the anthropometric dimensions and ranges of motion as defined in data sets in Appendix F, Physical Characteristics and Capabilities, Sections F.2 and F.3.

[Rationale: All crewmembers need to be able to perform any planned tasks efficiently and effectively. Physical crew interfaces need to be located within the visible and functional reach limits of the worst case (i.e., most limited) crewmember in his/her working posture using the most encumbering equipment and clothing anticipated. Design constraints may dictate layouts or tasks that force a crewmember to move, twist, or stretch into awkward positions. However, the system design must not require the crewmember to achieve ranges of motion outside those defined in Appendix F. When applied to suit design, the suit must allow an unpressurized and pressurized suited crewmember to achieve the entire range of motion defined in the appendix. The suit must be designed to allow for suited crewmembers to operate in an independently designed vehicle or habitat, and the vehicle or habitat must not require a range of motion a suit cannot provide.

A task analysis that identifies hardware interfaces and obstructed/confined/restrained reaches for planned tasks is used with Appendix F to define critical anthropometric dimensions and ranges of motion and provide design considerations for crew interfaces. The task analysis also identifies other parameters and constraints (e.g. mission phase, recumbent postures, etc.) that may require adjustments to the anthropometric data in the Appendix. Guidance on the evaluation of design for anthropometry and range of motion can be found in section 4.5 of the HIDH.

The intent of this requirement is to accommodate the entire potential user population, not just meet the criteria in the datasets, which provide the most frequently used values in standard reference postures. When a design requires a posture outside of the standard reference posture, such as rotation from upright to recumbent seating, minimum and maximum values for the new posture must be developed for the unique design posture.

Identification of a posture, dimension, or range of motion not provided in the table needs coordination and concurrence from NASA Stakeholders. When a system must accommodate a suited crewmember, an additional suited dataset can be provided that accurately identifies suited human dimensions. A tailored data set may be provided by NASA based on program or mission specific criteria, especially when a specific spacesuit has been identified.]

4.1.2 Body Mass, Volume, and Surface Area Data

[V2 4103] The system **shall** accommodate the body characteristic data for mass, volume, and surface area as defined in Appendix F, Physical Characteristics and Capabilities, Sections F.4, F.5, and F.6.

[Rationale: Depending on mission or design requirements, system developers could need body mass, volume, and body surface area data that accurately describe the entire size range of potential crewmembers.

Surface area data could be needed when assessing radiation exposure or designing a body contact cooling system. Volume data may be needed for center of gravity or buoyancy calculations.

Body mass data can describe both whole body mass and body segment mass. In addition to simple body mass, data includes centers of gravity and moments of inertia. Body mass data is important for multiple systems. Propulsion and dynamic systems calculations depend on accurate data of crewmember mass to size hardware systems and design proper vehicle dynamic controls. Body mass data is used to characterize forces exerted between crewmembers and equipment such as body support systems (e.g. seats, brackets, and restraints) under all anticipated acceleration and gravity environments. Body segment centers of gravity may be an important design consideration for crewmember balance and stability during dynamic mission phases or for understanding how loads are distributed during acceleration. Guidance on the evaluation of design using body characteristic data can be found in NASA/TP-2014-218556 Human Integration Design Process (HIDP).

The intent of this requirement is to accommodate the entire potential user population, not just meet the criteria in the datasets provided, which provide the most frequently used values. Identification of body characteristic data not provided in the table needs coordination and concurrence from NASA Stakeholders. A tailored set may be provided by NASA based on program or mission specific criteria.]

4.1.3 Crew Strength

All crewmembers need to be able to perform any planned tasks efficiently and effectively, without risk of injury and without undue concern of the hardware sustaining damage. Human-System Interfaces need to accommodate both the minimum and maximum anticipated strength of potential crewmembers. Strength refers to a person's ability to generate force. The system must withstand the load that is imparted and must not require excessive forces to operate.

4.1.3.1 Crew Operational Loads

[V2 4104] The system **shall** be operable by crew during all phases of flight, including prelaunch, ascent, orbit, entry, and postlanding, with the lowest anticipated strength as defined in Appendix F, Physical Characteristics and Capabilities, Section F.7.

[Rationale: All crewmembers need to be able to perform any planned tasks efficiently and effectively. The crew operating load data in Appendix F defines the lowest anticipated forces that can be applied by crewmembers in unsuited, suited-unpressurized, and suited-pressurized conditions, taking into account deconditioning and factors of safety for critical tasks. A task analysis that identifies planned crew tasks, hardware interfaces, expected postures, and task criticality, frequency, and duration is used with Appendix F to define the maximum acceptable value for actuation and continued operation of hardware interfaces. Guidance on the evaluation of design using crewmember strength data can be found in NASA/TP-2014-218556 Human Integration Design Process (HIDP).

The intent of this requirement is to accommodate the entire potential user population, not just meet the criteria in the datasets provided, which provide the most frequently used values.

Identification of postures or forces not provided in the table needs coordination and concurrence from NASA Stakeholders. A tailored data set may be provided by NASA based on program or mission specific criteria.]

4.1.3.2 Withstand Crew Loads

[V2 4105] The system **shall** withstand forces imparted by the crew during all phases of flight, including prelaunch, ascent, orbit, entry, and postlanding, as defined in Appendix F, Physical Characteristics and Capabilities, Section F.7 without sustaining damage.

[Rationale: Vehicle hardware are to be designed to withstand large forces exerted by a crewmember during nominal operations without breaking or sustaining damage that would render the hardware inoperable. Additionally, crew may exert high forces when operating controls in emergency situations, such as attempting to open a hatch for emergency egress. The resulting damage to equipment could make it impossible to respond safely to the emergency. To avoid overdesign, a task and error analysis which defines planned crew tasks, hardware interfaces, expected postures, and task criticality is used to identify which interfaces must tolerate maximum crew operational loads. This includes identifying critical hardware that may be inadvertently used as a mobility aid or restraint. Guidance on the evaluation of design using crewmember strength data can be found in NASA/TP-2014-218556 Human Integration Design Process (HIDP); information on task analysis process can be found in Section 4.1. Durability of the Structural Integrity of Hardware Due to Unintentional Crew Forces is addressed in [V2 9027] Protect Crew and Equipment.

The intent of this requirement is to accommodate the entire potential user population, not just meet the criteria in the datasets provided, which provide the most frequently used values. Identification of postures or forces not provided in the table needs coordination and concurrence from NASA Stakeholders. A tailored data set may be provided by NASA based on program or mission specific criteria.]

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[V2 4001] Requirement merged into [V2 4102], [V2 4103], [V2 4104], and [V2 4105].

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[V2 4002] Requirement merged into [V2 4102], [V2 4103], [V2 4104] and [V2 4105].

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[V2 4003] Requirement merged into [V2 4102], [V2 4103], [V2 4104] and [V2 4105].

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[V2 4004] Requirement merged into [V2 4102], [V2 4103], [V2 4104] and [V2 4105].

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[V2 4005] Requirement merged into [V2 4102].

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[V2 4006] Requirement merged into [V2 4102].

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[V2 4007] Requirement merged into [V2 4102].

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[V2 4008] Requirement merged into [V2 4102].

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[V2 4009] Requirement merged into [V2 4103].

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[V2 4010] Requirement merged into [V2 4103].

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[V2 4011] Requirement merged into [V2 4103].

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[V2 4012] Requirement split into [V2 4104] and [V2 4105].

4.2 Muscle Effects

[V2 4013] The effects of muscle endurance and fatigue **shall** be factored into system design.

[Rationale: Tasks with high force requirements and repetitive tasks (even with low force requirements) can cause fatigue. The crew task analysis is to identify factors that can lead to overexertion or fatigue such as task frequency, duration, repetitive motions, high forces, current and previous gravity environments and duration, suit configuration, etc. The applicable factors are needed for NASA to provide an appropriate strength dataset and they should - be considered in designs for crewmember operation. Apollo EVA crew reported forearm muscle fatigue due to repetitive force exertion to grasp and manipulate items while wearing pressurized gloves. The issue was exacerbated by the design of the gloves having fingers that returned to extended position rather than neutral, curved position requiring the crew to exert additional, unproductive movement and force. The effects of muscle fatigue may be mitigated through task design that includes providing mechanical aids, recovery rest periods, or varies the use of muscle groups.

4.3 Aerobic Capacity

[V2 4015] The system **shall** be operable by crewmembers with the aerobic capacity as defined in NASA-STD-3001, Volume 1.

[Rationale: An individual's aerobic capacity determines the ability to perform a task at a given level of work. The aerobic capacity in conjunction with the operational concept provides an upper bound for oxygen (O_2) demand, carbon dioxide (CO_2) production, heat rejection requirements, etc. This information is vital for all spacecraft Environmental Control and Life Support System (ECLSS) designs, including the EVA suits. This information would help in sizing the primary and emergency O_2 systems, scrubbers, etc., and help the engineers perform trade studies on various designs based on the operational scenarios and metabolic expenditure.]

5. PERCEPTION AND COGNITION

This section articulates human perceptual and cognitive characteristics that must be accommodated by the system design to support effective and efficient user performance. These characteristics can be described in terms of capabilities and limitations that vary such as age, sex, fatigue, and exposure to environmental factors. As there are limitations within the design of system components, there are limits to human capabilities. The environmental conditions of space flight can further degrade human capabilities. Systems need to be designed to support human perceptual and cognitive capabilities to meet system performance, safety, and mission requirements. Specific user performance and interface design requirements are in section 10, Crew Interfaces, of this NASA Technical Standard.

For detailed discussions regarding human performance capabilities, e.g., visual perception, auditory perception, cognition, and workload, see chapter 5, Human Performance Capabilities, of the HIDH. For detailed discussions regarding the design of user interfaces, e.g., visual acquisition of displays, visual displays, layout of displays and controls, see chapter 10, Crew Interfaces, of the HIDH.

5.1 Perceptual and Cognitive Characteristics and Capabilities

5.1.1 Visual Capabilities

Visual capabilities include, at a minimum, visual acuity, spatial contrast sensitivity, visual accommodation, field of regard, color discrimination, stereoscopic depth perception, and temporal contrast sensitivity. Further explanation of these terms can be found in Appendix C, Definitions, of this NASA Technical Standard.

[V2 5001] The system **shall** accommodate anticipated levels of crew visual capabilities under expected task demands.

[Rationale: Design of interface elements such as text, graphics, and icons, as well as design of the display itself and its placement relative to the user, are to ensure that relevant visual information is visible and readable (text) or interpretable (graphical icons or symbols) while a crewmember performs mission tasks. Determination of anticipated levels of crewmember capability and anticipated levels of task demands is based on a detailed task analysis.]

5.1.2 Auditory Perceptual Capabilities

[V2 5002] The system **shall** accommodate anticipated levels of crew auditory perceptual capabilities under expected task demands.

[Rationale: Auditory capabilities include, at a minimum, absolute threshold of hearing, auditory localization, and speech intelligibility. Auditory localization refers to the aural sensation of the location of a sound in space. Speech intelligibility refers to the ability to correctly identify speech material (typically words) in accordance with a standardized testing method. Maximum limits are provided in Section 6.6.1, Acoustic Limits, to avoid injury to crewmember.

Audio-communications can play an essential role in completing mission operations. This is especially true for operations that require coordination of individuals remote from each other (a feature of all space missions). Audio-communications are also critical to successful completion of non-scripted operations such as emergency recovery from an off-nominal event. Communication engineering calculations require metrics for ensuring speech intelligibility and quality under all mission phases. All vehicle systems are to be designed with respect to the noise and vibration environment and other sources of auditory masking (from excessive noise). Vehicle systems are to also accommodate suited (LEA, IVA and EVA) versus unsuited conditions, accounting for auditory capabilities at identified suit pressures. Determination of anticipated levels of crew capability and anticipated levels of task demands can be made through a detailed task analysis. For detailed discussions regarding the effects of space flight on auditory capabilities, see chapter 5, Human Performance Capabilities, of the HIDH.]

5.1.3 Sensorimotor Capabilities

[V2 5003] The system **shall** accommodate anticipated levels of crew sensorimotor capabilities under expected task demands.

[Rationale: Sensorimotor functional capabilities include balance, locomotion, eye-hand coordination, visual control, tactile perception, and orientation perception. Controls and displays can provide information to the operator through sensorimotor perception channels. Requirements are to be written to ensure successful use of that information channel. Transmittal of information through sensorimotor channels is dependent on the nature of the information (rate, direction, quantity, etc.), clothing worn by the operator (gloves, footwear, helmet, etc.), control and display characteristics (control shape, control forces, display orientation, etc.), and the environment (vibration, lighting, acceleration, gravity, etc.). Determination of anticipated levels of crew capability and anticipated levels of task demands is based on a detailed task analysis. For detailed discussions regarding the effects of space flight on

vestibular/sensorimotor alterations, see chapter 5, Human Performance Capabilities, of the HIDH.]

5.1.4 Cognitive Capabilities

[V2 5004] The system **shall** accommodate anticipated levels of crew cognitive capabilities under expected tasks demands.

[Rationale: Cognitive capabilities include attention, memory, decision making, problem solving, logical reasoning, and spatial cognition applied in both an individual and team. Accommodating cognitive performance capabilities is important to ensure optimal task performance and crew safety. Design of hardware, including displays and controls, and software, including problem-solving aids, is to take into account the capabilities and limitations of humans to acquire, interpret, and retain information such that the relevant information is available and intelligible. Tasks assigned to humans are to be those best-suited to humans (i.e., dealing with unexpected events or complex problem solving). Tasks requiring memory, calculations, and speed are to be assigned to computer automation. This approach considers the relative strengths of the human versus the computer and minimizes risk of errors by assigning tasks accordingly. This is especially important during space flight, where microgravity can cause deconditioning and affect spatial orientation, and where stress can affect several cognitive processes. For detailed discussions regarding the effects of stress on cognitive performance, see chapter 5, Human Performance Capabilities, of the HIDH. Determination of anticipated levels of crew capability and anticipated levels of task demands is based on a detailed task analysis with consideration of all nominal, off-nominal, and emergency scenarios, including those of low probability.]

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[V2 5005] Requirement merged into [V2 10003].

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[V2 5006] Requirement moved to Section 10.1.1.

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[V2 5007] Requirement moved to Section 10.1.1.

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[V2 5008] Requirement merged into [V2 5007].

6. NATURAL AND INDUCED ENVIRONMENTS

Natural and induced environmental factors include air, water, contamination, acceleration, acoustics, vibration, radiation, and temperature. Environmental design factors that can enhance *human performance such as crew station layout and lighting are discussed in section 8, Architecture, in this NASA Technical Standard. Overall, the system's environment is to be compatible with tasks to be performed and promote crew health and performance.*

6.1 Trend Analysis of Environmental Data

[V2 6001] The system **shall** provide environmental monitoring data in formats compatible with performing temporal trend analyses.

[Rationale: Requirements are to consider all environmental parameters that may require trend analysis for a given mission. Trending of environmental parameters such as internal atmosphere constituents, temperature, humidity, water, acoustics, radiation, acceleration and dynamic loads see sections 6.2 through 6.8 in this NASA Technical Standard for the detailed requirements) is necessary for both anticipating harmful conditions before they occur and troubleshooting using previously stored data. To properly trend, aspects of the data such as the measurement rate are also to be considered, as some parameters may otherwise only be measured infrequently.]

6.2 Internal Atmosphere

A safe, breathable atmosphere is critical to human health and performance. Early identification of potential air quality issues enables mitigation by design. Monitoring atmospheric quality and evaluating trends are essential. The system is to be robust enough to control or allow crew control of atmospheric pressure, humidity, temperature, ventilation flow rate, airborne particulates, inspired partial pressure of O_2 *(*P_IO_2*), partial pressure of* CO_2 *(*$ppCO_2$*), and trace contaminants within ranges necessary to maintain task performance and human health and safety. Although the following requirements address these components individually, they must be considered as a whole because they are dependent on each other. Additional information about the interplay among internal atmosphere components and the effects on the human is available in section 6.2 of the HIDH. An iterative process should be employed to integrate the human system internal atmospheric limits into the design process, ensuring optimization of the design to afford the most protection possible, within other constraints of the vehicle systems. Atmospheric requirements specific to suited operations can be found in section 11.1, Suit Design and Operations, in this NASA Technical Standard.*

6.2.1 Atmospheric Constituents

6.2.1.1 Inert Diluent Gas

[V2 6002] Cabin atmospheric composition **shall** contain at least 30% diluent gas (assuming balance oxygen).

[Rationale: This mitigates clinically significant absorption atelectasis. The assumption is that the diluent gas will be nitrogen (N_2*). Use of helium (He) or argon (Ar) has been considered, but would affect decompression sickness (DCS), thermal and ventilation requirements. Validation and verification of alternate diluent gases must be adjudicated by program medical team and*

another requirement set be developed. Measurable oxygen absorption atelectasis (lung collapse) occurs with fractions of oxygen above 50%. A diluent gas is required to prevent excessive levels of oxygen absorption atelectasis during prolonged exposures, in addition to reducing the ignition/flammability threshold. Unacceptable risk occurs when breathing less than 20% diluent. Although oxygen absorption atelectasis can be observed in the 25-50% diluent range, clinical and space flight experience shows that diluent fractions as low as 25% maintain acceptable levels of pulmonary function for long duration space flight activities. The choice of diluent gas is dependent on many factors, including physiological activity and contribution to (DCS). Reference [V2 6003] O_2 Partial Pressure Range for Crew Exposure in this NASA Technical Standard for hyperoxic/hypoxic limits. Clinically significant atelectasis is unlikely when combining the expected habitat total pressures (typically 8.2 to 14.7 psia) with the hyperoxic bounds established in Table 1, Inspired Oxygen Partial Pressure Exposure Ranges.]

6.2.1.2 O_2 Partial Pressure Range for Crew Exposure

[V2 6003] The system **shall** maintain inspired oxygen partial pressure (P_IO_2) in accordance with Table 1, Inspired Oxygen Partial Pressure Exposure Ranges.

[Rationale: For all systems, the range of ambient dry-gas ppO_2 is to be considered in the context of P_IO_2. Since physiological limits for hypoxic (and hyperoxic) exposure during space flight are unknown, systems designed for humans are to be normoxic unless strong rationale is provided for an alternative suggestion. For confined and enclosed spaces at sea level, the Occupational Safety and Health Administration (OSHA) defines oxygen-deficient atmosphere as <19.5% oxygen by volume, and oxygen-enriched atmosphere as >23.5% oxygen by volume (Electronic Code of Federal Regulations, 1910.146(b)(3), current through July 29, 2021) with a correlating normoxic P_IO_2 range between 139-168 mmHg. The OSHA-enriched atmospheric limit is more applicable to material flammability than human hyperoxic limit. Hyperoxia limits are provided to allow needed prebreathe and if necessary, DCS treatment. It is generally accepted that there are no medical or performance issues with constant exposure to one-half an atmosphere of O_2 partial pressure (Clarke, J.M., Oxygen Toxicity [Chapter 6]. The Physiology and Medicine of Diving [4th ed], Bennett, P.B., Elliott, D.H. [eds]. W.B. Saunders Company Ltd: Philadelphia, 1993, pp. 153-69); this is a pp O_2 of 7.35 psia, or 380 mmHg, or as P_IO_2, it is 333 mmHg. NASA operates the extravehicular mobility unit (EMU) at 4.3 psia with 100% O_2, so this is a pp O_2 of 222 mmHg; or as P_IO_2, it would be 175 mmHg, and there are no performance or medical issues to date with this limit. A practical and defensible hyperoxic exposure limit would be a P_IO_2 of 333 mmHg with the assumption that adaptations to microgravity do not modify this terrestrial limit. As far as a hypoxic limit, it has been shown that a mildly hypoxic vehicle system atmosphere as part of a denitrogenation protocol to reduce the risk of DCS is advantageous during space flight (e.g., shuttle 10.2 psia/26.5% O2), as well as recommended by the Exploration Atmospheres Working Group and endorsed by Human Exploration and Operations Mission Directorate (Exploration Atmospheres, HEOMD memo, February 2013). There is no indication on Earth that living and working with chronic P_IO_2 of 127 mmHg degrades health or performance. There are no indications or predictions based on limited past experience that extending exposure time with P_IO_2 of 127 mmHg in micro or partial gravity past 7 days leads to degradation of health or performance in otherwise healthy astronauts. There is no opportunity to

collect data in microgravity with PIO2 of 127 mmHg to cover the durations of Exploration Class missions, so a health monitoring and mitigation plan are required to implement this condition. These guiding P_IO_2 values may change as further research yields information to better define the physiological limits and acceptable duration for an alternative space flight system environment.]

Table 1—Inspired Oxygen Partial Pressure Exposure Ranges

Inspired O_2 partial pressure $P_IO_2 = (PB-47)*F_IO_2$	Normoxia Target Range	Indefinite Hyperoxia Upper Limit	Short-Term Hyperoxia Upper Limit	Mild Hypoxia Lower Limit
P_IO_2 (mmHg) $P_IO_2 = (PB-47)* F_IO_2$	145-155	356	791	127
P_IO_2 (psia)	2.80-3.00	6.89	15.30***	2.46
Acceptable Duration	Indefinite	Indefinite	6-9 Hours *	Indefinite with monitoring**
Examples	Habitat and Spacesuit Minimum	EVA and Cabin Depress In-Suit Survival	O_2 Prebreathe for EVA Preparation	EVA Preparation (ISS Campout, Shuttle 10.2, Exploration Atmosphere of 8.2 psia and 34% O_2)

PB – Ambient Barometric Pressure
F_I – Fractional concentration of inspired oxygen
F_IO_2 – The dry-gas decimal fraction of ambient O_2
**From Johnson Procedural Requirements (JPR) 1830.6 (REQUIREMENTS APPLICABLE TO PERSONNEL PARTICIPATING IN DIVING, HYPER/HYPOBARIC CHAMBERS, AND PRESSURIZED SUIT OPERATIONS). Page 15, subsection 4.2: Limitations during Oxygen Breathing," shows the limits for prebreathe in a spacesuit. The limit is nine hours when that is the only exposure to enriched O_2 in a 48-hour period. The limit is six hours when it is the only exposure to enriched O_2 in a 24-hour period and also states that consecutive daily exposures are not to exceed five consecutive days.*
***There is no opportunity to collect data in microgravity with P_IO_2 of 127 mmHg to cover the durations of Exploration Class missions, so a health monitoring and mitigation plan are required to implement this condition*
****This P_IO_2 may be exceeded during DCS treatment.*

6.2.1.3 Nominal Vehicle/Habitat Carbon Dioxide Levels

[V2 6004] The system **shall** limit the average one-hour CO_2 partial pressure ($ppCO_2$) in the habitable volume to no more than 3 mmHg.

[Rationale: Achieving this level is dependent on individual and total crew generation of CO_2 for all planned activities (factoring in metabolic rates and respiratory quotient), appropriate CO_2 scrubbing and adequate ventilation flow rates to ensure that no localized pockets of CO_2 are generated throughout the habitat. Considerations from other payloads that generate CO_2 are to be taken into account of these totals.

Note: Off-nominal CO_2 values are not included within this NASA Technical Standard due to the unique circumstances of each mission (expected human performance, duration of exposure, access to medical care, etc.) and will be derived as a lower level program/project requirement.]

6.2.2 Atmospheric Pressure

6.2.2.1 Total Pressure Tolerance Range for Indefinite Crew Exposure

[V2 6006] The system **shall** maintain the pressure to which the crew is exposed to between 26.2 kPa < pressure ≤ 103 kPa (3.8 psia < pressure ≤ 14.9 psia) for indefinite human exposure without measurable impairments to health or performance.

[Rationale: Designers and physiologists have to evaluate and trade off the various atmospheric combinations. A low total pressure is desirable because it allows simple transfer to a low-pressure EVA suit. (Low pressure EVA suits are less stiff and allow greater range of motion.) Low total pressure requires a higher percentage of oxygen in the atmosphere to provide an acceptable ppO_2. Oxygen-rich atmospheres, however, present safety hazards because of their ability to feed fires. The lowest pressure at which normoxia (P_IO_2 = 149 mmHg) is maintained at 100% O_2 is 3.8 psia. Total pressure has to be considered in conjunction with O_2 and CO_2 requirements. Under certain spacesuit operations (e.g., DCS treatment, leak checks), the crewmember may be exposed to pressure above or below this range for a limited period of time.]

6.2.2.2 Rate of Pressure Change

[V2 6007] For pressure changes >1.0 psi, the rate of change of total internal vehicle pressure **shall not** exceed 13.5 psi/min.

[Rationale: This rate of pressure change is used across numerous environments and provides a good boundary for human tolerance. This rate of change helps decrease risk of injury to crewmembers' ears and lungs during depressurization and repressurization but does not replace the [V2 6150] Barotrauma Prevention requirement. Microgravity may have affected head and sinus congestion and is therefore much more conservative than the 30 psi/min (1550 mmHg/min) (75 ft/min) descent rate limit allowed by the U.S. Navy Diving Manual. The negative rate of change limit is consistent with the U.S. Navy Diving Manual 13.5 psi/min (700 mmHg/min) (30 ft/min) ascent rate allowance, which is used primarily for DCS prevention, not barotrauma prevention. For transient pressure changes ≤ 1.0 psi, the rate of change of total internal vehicle pressure can exceed 13.5 psi/min.]

6.2.2.3 Barotrauma Prevention

[V2 6150] During a commanded pressure change, the system **shall** pause within 1 psi of the pause command being issued by the unsuited or suited crewmember, with ability to increase or decrease pressure as needed after the pause.

[Rationale: During all intentional pressure changes, crewmembers may need to pause the pressure change within the system allowing additional time to adjust to the change in pressure and to avoid barotrauma. If the pause does not alleviate discomfort, the crewmember needs to be able to reverse the direction of the pressure change. This could be necessary if a crewmember is unable to equalize pressure in their ears and sinuses.]

6.2.2.4 Decompression Sickness (DCS) Risk Identification

[V2 6008] Each program **shall** define mission unique DCS mitigation strategies to achieve the level of acceptable risk of DCS as defined below within 95% statistical confidence:

a. DCS ≤ 15% (includes Type I or isolated cutis marmorata).
b. Grade IV venous gas emboli (VGE) ≤ 20%.
c. Prevent Type II DCS.

[Rationale: DCS risk limits have been defined to develop coordinated requirements for the habitat (e.g., vehicle, EVA suit) including total pressure, ppO_2 and prebreathe before vehicle or suit depressurization, which are all variables in DCS risk.]

6.2.2.5 Decompression Sickness Treatment Capability

[V2 6009] The system **shall** provide DCS treatment capability.

[Rationale: DCS is a potential hazard of space flight and EVA because of changes in the operational pressure environment. Rapid and appropriate intervention is required to optimize the outcome for the affected crewmember. If treatment for DCS is instituted quickly, the outcome of therapy has a higher probability of success and will likely require less magnitude and duration of hyperbaric O_2 therapy.

It is important, therefore, to have the crewmember back to his/her initial saturation pressure as soon as possible, which may resolve DCS symptoms. Initial saturation pressure is defined as the highest pressure to which the crewmember has been exposed during the 36 hours before beginning the EVA. If not addressed quickly, higher pressures may be required to address DCS symptoms. The U.S. Navy Treatment, Table 6, Oxygen Treatment of Type II Decompression Sickness (treatment in a hyperbaric treatment facility) found in the U.S Navy Diving Manual, is the terrestrial standard for treating most forms of DCS; however, the terrestrial standard may not be achievable, or required, because the resources required to support it would be prohibitive, and the expected outcomes from sub-terrestrial standard therapy are likely to be adequate for altitude-induced DCS symptoms.]

6.2.3 Post Landing Relative Humidity (RH)

[V2 6011] For nominal post landing operations, the system **shall** limit RH to the levels in Table 2, Average Relative Humidity Exposure Limits for Post Landing Operations.

[Rationale: Average humidity is to be maintained above the lower limits stated to ensure that the environment is not too dry for the nominal functioning of mucous membranes. During low humidity exposures, additional water is to be provided to the crew to prevent dehydration. Humidity is to be maintained below the upper limits for crew comfort to allow for effective evaporation and to limit the formation of condensation. In unsuited scenarios, high RH may interfere with the nominal evaporation process that enables perspiration to cool the body. Thus,

high RH in warm environments can pose an additional hazard for core body temperature excess.]

Table 2—Average Relative Humidity Exposure Limits for Post Landing Operations

Average RH	Time Allowed
25% < RH ≤ 75% (nominal range[1])	Indefinite[2]
75% < RH ≤ 85%	24 hr[3]
85% < RH ≤ 95%	12 hr[3]
95% < RH	8 hr[3]

1. Nominal humidity range is included for completeness.
2. Assumes temperature is within nominal range in accordance with requirement [V2 6012] Crew Health Environmental Limits in this NASA Technical Standard.
3. Only after doffing a suit post landing; duration may be shorter if temperature is outside nominal range (specified in requirement [V2 6012] Crew Health Environmental Limits in this NASA Technical Standard).

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[V2 6010] Requirement merged into [V2 6012].

6.2.4 Temperature and Humidity for Crew Health and Performance

6.2.4.1 Crew Health Environmental Limits

[V2 6012] The system **shall** maintain levels of cabin humidity and temperature within the boundaries of the Operating Limits as shown in Figure 2, Crew Health Environmental Limits, to protect for crew health during pressurized operations when crew occupies the cabin, excluding suited operations, ascent, entry, landing, and post landing.

[Rationale: The intent of the Crew Health Environmental Limits is to provide the range of cabin humidity and temperature that protects crew health. Figure 2 is based on ASHRAE 55 and anchored at 18°C and 75% humidity on the upper left corner and 27 °C and 25% humidity on the lower right corner. Operations outside of these boundaries may cause crewmembers to experience health impacts (dry, stuffy and/or irritated mucous membranes), skin rashes (due to microbial growth at high humidity levels) thermal discomfort (overheating depending on tasks) and/or decreased performance. From an engineering perspective, average humidity is to be maintained above this lower limit (25%) to ensure that the environment is not too dry to prevent static electricity buildup within the cabin, which could pose an electrical hazard to crew and a possible ignition hazard. Refer to [V2 6013] Crew Health and Performance Environmental Zone for the range that protects for both health and performance. This requirement does not apply to EVA suits. Corresponding EVA suit requirements addressing temperature, humidity, pressure, and other elements that affect comfort in a spacesuit are defined in section 11 of this NASA Technical Standard.]
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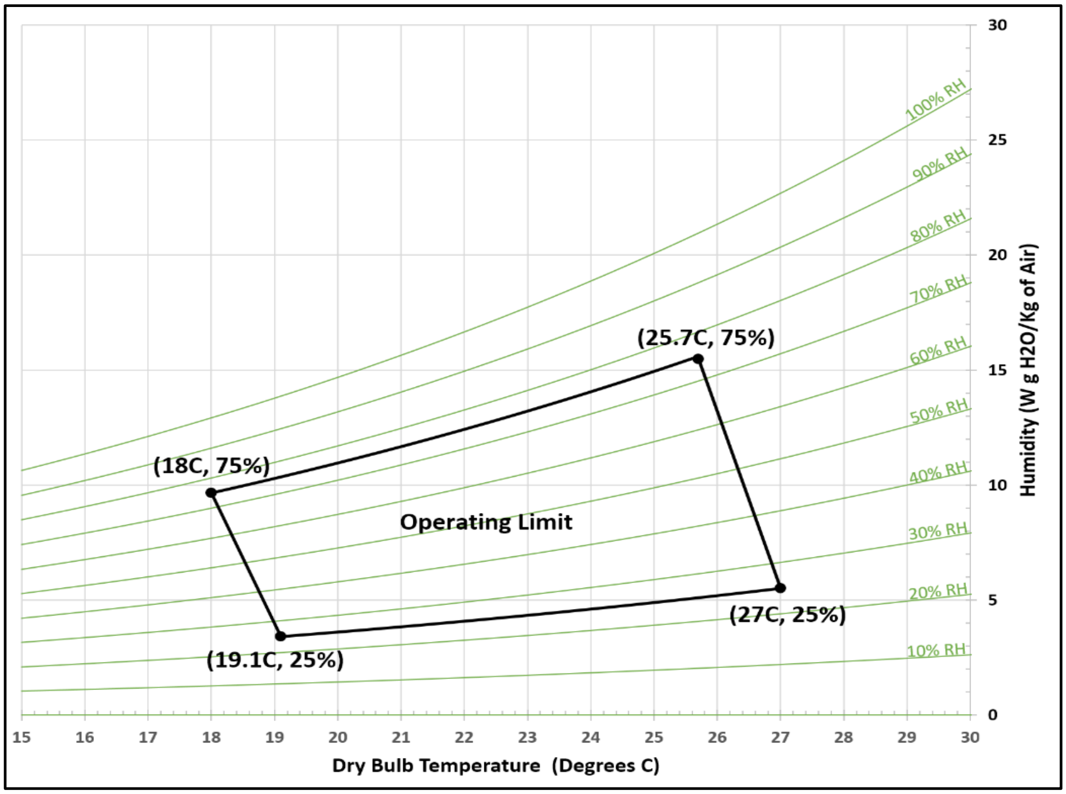

Figure 2—Crew Health Environmental Limits

6.2.4.2 Crew Performance Environmental Zone

[V2 6013] The system **shall** be capable of reaching atmospheric humidity and temperatures of nominally occupied habitable volumes within the zone provided in Figure 3, Crew Performance Environmental Zone, during all nominal operations, excluding suited operations, ascent, entry, landing, and post landing.

[Rationale: This temperature zone is defined as the operating zone of environmental conditions in which humans can achieve thermal comfort and not have their performance of routine activities affected by thermal stress. Operating outside of this zone will cause performance decrements and impact productivity. Due to individual variability among crewmembers and the likelihood of different crewmembers performing different tasks at different metabolic rates, it is necessary to have the capability to change temperature set points, adjust localized air flow, and/or have various clothing options available to achieve thermal comfort for all crew. Studies of office working environments and OSHA recommendations generally find these atmospheric parameters (20°C -25°C and 30-60% humidity) to support human comfort and performance (T.M. Ikaheimo, 2014; Seppanen, Fisk, & Lei, 2006; OSHA Policy on Indoor Air Quality: Office Temperature/Humidity and Environmental Tobacco Smoke, 2003).]

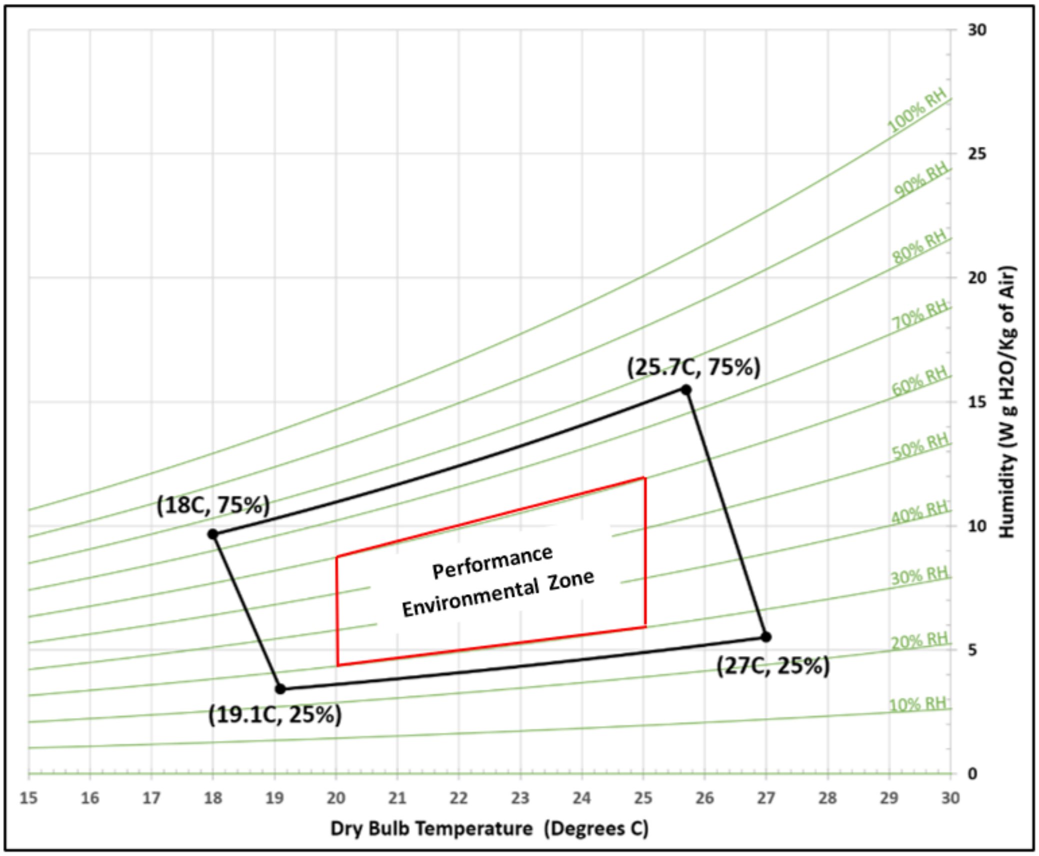

Figure 3—Crew Performance Environmental Zone

6.2.4.3 Temperature Selectability

[V2 6151] The system **shall** provide selectable set points for internal atmosphere temperature in step sizes no greater than 0.5°C increments in the habitable volume.

[Rationale: The intent of this requirement is to allow the crew to adjust the temperature to accommodate crew performance and provide some adjustment for crew preference. It is expected that the system can be set to temperatures in the environmental operating range (per [V2 6012] Crew Health Environmental Limits) and the system will accommodate those temperatures if the capability exists.]

6.2.4.4 Temperature Adjustability

[V2 6152] The system **shall** be capable of adjusting temperature in the habitable volume by at least 1°C/hr.

[Rationale: The cabin temperature needs to be capable of being adjusted in a timely manner (1° Celsius per hour) in order to accommodate real-time crew activities, performance, and crew preference.]

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[V2 6014] Requirement merged into [V2 6012].

6.2.4.5 Environmental Control

[V2 7041] The system environmental control **shall** accommodate the increased O_2 consumption and additional output of heat, CO_2, perspiration droplets, odor, and particulates generated by the crew in an exercise area.

[Rationale: The ppO_2 in the exercise area(s) is to be maintained at normal levels; otherwise, the required physiological capabilities of crewmembers may be impaired. This requirement also addresses any particulate that may be generated by the exercise activity, e.g., skin, hair, or lint from clothing or other materials.]

6.2.5 Atmospheric Control

[V2 6017] The system **shall** allow for local and remote control of atmospheric pressure, humidity, temperature, ventilation, and ppO_2.

[Rationale: The ability to control atmospheric conditions is important for crew comfort, e.g., temperature and humidity, and for mission tasks, e.g., ppO_2 and total pressure for expected cabin depressurization, to ensure efficient and effective performance. This requirement does not apply to spacesuits. The corresponding spacesuit requirement is defined in requirement [V2 11033] Suited Thermal Control, in this NASA Technical Standard. The ability to adjust atmospheric parameters remotely is important for cases in which a crewed vehicle is to dock with an uncrewed vehicle whose atmosphere is to be habitable before ingress. This may be done from other spacecraft located in microgravity, extraterrestrial body surfaces, or Earth- or lunar-based control centers

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[V2 6019] Requirement merged into [V2 6017].

6.2.6 Atmospheric Data Availability

6.2.6.1 Atmospheric Data Recording

[V2 6020] For each isolatable, habitable compartment, the system **shall** automatically record pressure, humidity, temperature, ppO_2, and $ppCO_2$ data continuously.

[Rationale: Access to atmospheric data is needed for each habitable compartment (that can be isolated with a pressure hatch) to which the crew has access, as each of these parameters is critical to crew health and comfort. Additionally, the ability to view past recorded data helps to prevent environmental conditions that could harm the crew or vehicle and can aid in the effort to

troubleshoot problems. This requirement does not apply to spacesuits. The corresponding spacesuit requirement is defined in requirement [V2 11034] Suited Atmospheric Data Recording, in this NASA Technical Standard.]

6.2.6.2 Atmospheric Data Displaying

[V2 6021] The system **shall** display real-time values for pressure, humidity, temperature, ppO_2, and $ppCO_2$ data to the crew locally and remotely.

[Rationale: These atmospheric parameters are critical to human health and comfort, and access to this atmospheric data needs to be provided to the crew. The crew needs to view the environmental status in real time to help prevent environmental conditions that could harm them or the vehicle. This requirement does not apply to spacesuits. The corresponding spacesuit requirement is defined in requirement [V2 11035] Suited Atmospheric Data Displaying in this NASA Technical Standard.]

6.2.7 Atmospheric Monitoring and Alerting

6.2.7.1 Atmospheric Monitoring and Alerting Parameters

[V2 6022] The system **shall** alert the crew locally and remotely when atmospheric parameters, including atmospheric pressure, humidity, temperature, ppO_2, and $ppCO_2$ are outside safe limits.

[Rationale: Systems are to be capable of alerting the crew when atmospheric parameters are outside set limits so the crew can take appropriate actions to maintain health and safety. See sections 10.3.4, Audio Displays, and 10.7.2, Caution and Warning, in this NASA Technical Standard for additional information. This requirement does not apply to spacesuits. The corresponding spacesuit requirement is defined in requirement [V2 11036] Suited Atmospheric Monitoring and Alerting, in this NASA Technical Standard.]

6.2.7.2 Trace Constituent Monitoring and Alerting

[V2 6023] The system **shall** monitor trace volatile organic compounds (VOCs) in the cabin atmosphere and alert the crew locally and remotely when they are approaching defined limits.

[Rationale: Monitoring and alerting are required to identify when hazardous contaminants are detected and to alert the crew so they can take appropriate actions to maintain health and safety. Trace contaminant monitoring is important for identifying a wide range of contaminants that may impact human health and safety, including toxic substances that cannot be predicted now or substances that are not normally thought of as part of the atmosphere. Accepted limits may be based on JSC-20584, Spacecraft Maximum Allowable Concentrations (SMACs), or on agreements from international partners. There may be specific mission scenarios (e.g., short-duration missions and alternate controls) where trace contaminant monitoring may not be required.]

6.2.7.3 Combustion Monitoring and Alerting

[V2 6024] The system **shall** monitor in real-time the toxic atmospheric components listed in Table 3, Recommended Combustion Product (CP) Monitoring Ranges, that would result from pre-combustion and combustion events in the ranges and with the accuracy and resolution specified in the table, and alert the crew locally and remotely in sufficient time for them to take appropriate action.

[Rationale: Monitoring of toxic by-products of combustion is generally used for operational decisions and response. Because of the extreme danger of combustion in a spacecraft, combustion product monitors are to be readily accessible and provide quick, stable, and accurate readings. Monitoring and alerting are required to identify when toxic combustion products are present and to notify the crew to take appropriate actions to maintain health and safety.]

Table 3—Recommended Combustion Product (CP) Monitoring Ranges

CP Target Required		Range[a]	Accuracy[b]	Resolution
CO		5-1000 ppm	±10%	1 ppm
HCN		2-50 ppm	±25%	1 ppm
Acid Gases (Hydrogen Halides)	HCl	2-50 ppm	±25%	1 ppm
	HF	2-50 ppm	±25%	1 ppm
	OR			
	HXb	2-50 ppm	±25%	1 ppm

a ppm is parts-per-million by volume at 1 atm
b accuracy across full listed range
c HX = the total concentration of halide acid gases, i.e., [HCl] + [HF] + [HBr]
Source: V.E. Ryder (2012). Volatile Combustion Product Monitoring in Spacecraft, TOX-VER-2016-03

6.2.7.4 Contamination Monitoring and Alerting

[V2 6025] The system **shall** monitor and display atmospheric compound levels that result from contamination events, e.g., toxic release, systems leaks, or externally originated, before, during, and after an event and alert the crew locally and remotely in sufficient time for them to take appropriate action.

[Rationale: Alerting the crew when contaminants are present is necessary for them to take appropriate action to maintain health and safety. In addition, monitoring after the event is important to verify that levels are safe for human exposure. Monitoring is required to identify when components are detected so that alerting can occur. Potential contaminants, e.g., hydrazine, monomethylhydrazine (MMH), unsymmetrical dimethylhydrazine (UDMH), nitrogen tetroxide/nitrogen dioxide and ammonia, need to be monitored after EVA.]

6.2.7.5 Celestial Dust Monitoring and Alerting

[V2 6153] The vehicle **shall** monitor celestial dust and alert the crew locally and remotely when they are approaching defined limits.

[Rationale: Celestial dust includes, but is not limited to, lunar, Martian and other extraterrestrial bodies. In-flight monitoring of habitable environments is required to characterize concentrations of celestial dust which enables any necessary crew action to maintain health and safety, tracking of average exposure, while also informing necessary treatment options after the mission, and providing a record of crew exposures. Lunar dust monitoring frequency and particle size fraction is dependent on mission characteristics and whether crew health concerns are based on chronic or acute exposure considerations as noted in [V2 6053] Lunar Dust Contamination. There may be other specific mission scenarios (e.g., surface launch vehicle docking to orbital vehicle) where dust monitoring may be required.]

6.2.8 Atmospheric Ventilation

6.2.8.1 Nominal Vehicle/Habitat Atmospheric Ventilation

[V2 6107] The system **shall** maintain a ventilation rate within the internal atmosphere that is sufficient to provide circulation that prevents CO_2 and thermal pockets from forming, except during suited operations, toxic cabin events, or when the crew is not inhabiting the vehicle.

[Rationale: Crew and equipment give off heat, moisture, and CO_2 that will lead to parameters outside the bounds of environmental requirements if adequate ventilation is not provided. Maintaining proper ventilation within the internal atmosphere is necessary to ensure that stagnant pockets do not form, and the temperature, humidity, and atmospheric constituents are maintained within their appropriate ranges. Similar values have been used on the International Space Station (ISS). Exceptions and more detail on ventilation rate measurement are listed in the verification requirement. The two-thirds value for atmosphere velocities in the requirement has historically proven to be a reasonable balance between design constraints such as power, acoustics, and safety. The effective atmosphere velocity range of 4.57-36.58 m/min (15-120 ft/min) pertains to the time averaged velocity magnitudes in the crew occupied space using averages over time periods sufficient to achieve stability. This range is considered sufficient to provide circulation that prevents CO_2 and thermal pockets from forming. Cabin ventilation is not required during suited operation since the suit will provide necessary air circulation. Fire or any toxic release into the atmosphere are examples of periods during which the mentioned ventilation rates are not in the best interest of air quality and crew health. In those cases, the ventilation system may need to be shut down to protect the safety of the crew.

6.2.8.2 Off-Nominal Vehicle/Habitat Atmospheric Ventilation

[V2 6108] The system **shall** control for ppO_2, $ppCO_2$, and relative humidity during off-nominal operations, such as temporary maintenance activities in areas not in the normal habitable volume.

[Rationale: The crew may be required to perform maintenance behind a panel in an area that is not part of the normal habitable volume, and which therefore does not have ventilation. Maintaining proper ventilation within the internal atmosphere is necessary to ensure that stagnant pockets do not form and the temperature, humidity, and atmospheric constituents are maintained within their appropriate ranges. See [V2 6003] O_2 Partial Pressure Range for Crew

Exposure, [V2 6004] Nominal Vehicle/Habitat Carbon Dioxide Levels, and [V2 6012] Crew Health Environmental Limits, in this NASA Technical Standard. Examples of historical ventilation techniques include equipment such as flexible (reconfigurable) ducting, portable fans, or diverters.]

6.2.9 Atmospheric Contamination

Note: For contamination, units of measure are expressed in metric units only in the sections that follow.

6.2.9.1 Atmosphere Contamination Limit

[V2 6050] The system **shall** limit gaseous pollutant accumulation in the habitable atmosphere below individual chemical concentration limits specified in JSC-20584, Spacecraft Maximum Allowable Concentrations for Airborne Contaminants (SMACs).

[Rationale: Exposure limits for expected airborne spacecraft contaminants are established to protect crewmembers from illness and injury. The SMACs provide guidance for short-term (1 and 24 hours), medium-term (7 and 30 days), and long-term (180 days and 1,000 days) exposure of these constituents. The SMACs take into account several unique factors of human space flight missions, including the stress on human physiology, the uniform good health of astronauts, and the absence of pregnant or very young individuals. Short-term SMACs are intended for off-nominal events and are not to be used for system design or evaluation of routine exposures. Considerations are to be taken for scenarios where there is a period of dormancy or uncrewed operations.]

6.2.9.2 Particulate Matter

[V2 6052] The system **shall** limit the habitable atmosphere particulate matter concentration for total dust to <3 mg/m^3 with a crew generation rate of 1.33 mg/person-minute, and the respirable fraction of the total dust <2.5 µm (micrometer) in aerodynamic diameter to <1 mg/m^3 with a crew generation rate of 0.006 mg/person-minute.

[Rationale: These values were derived by applying a factor of five to the OSHA limits for nuisance dusts, which is the best analog for the ordinary dust present in spacecraft. They do not apply to reactive dust, e.g., lithium hydroxide (LiOH) or extraterrestrial dust. The factor of five is applied to adjust from intermittent occupational exposure to continuous space flight exposure. The basis for the particulate matter generation rates is documented in ICES-2019-58, The Impacts of Cabin Atmosphere Quality Standards and Control Loads on Atmosphere Revitalization Process Design. The generation rate for the respirable fraction of the total dust was calculated by adding the generation rate for particles <1 µm in diameter and one-half the generation rate for particles with diameters between 1 µm and 5 µm.]

6.2.9.3 Lunar Dust Contamination

[V2 6053] The system **shall** limit the levels of lunar dust particles less than 10 µm in size in the habitable atmosphere below a time-weighted average of 0.3 mg/m^3 during intermittent daily exposure periods that may persist up to 6 months in duration.

[Rationale: This limit was based on detailed peer-reviewed studies completed by the Lunar Atmosphere Dust Toxicity Assessment Group (LADTAG) and is specific to the conditions relevant to the lunar surface, i.e., this requirement would not necessarily be applicable to other missions. The requirement assumes that the exposure period is episodic and is limited to the time before ECLSS can remove the particles from the internal atmosphere (assumed as eight hours post introduction). Although the requirement is being conservatively applied to all inhalable particles (all particles ≤10 µm), it is most applicable to dusts in the respirable range (≤2.5 µm) that can deposit more deeply into the lungs. Studies show that the particle size of lunar dust generally falls within a range of 0.02-5 µm . The ability to meet this requirement will depend upon factors such as the level of lunar dust introduction and ECLSS removal rates. The monitoring of dust is captured in [V2 6153] Celestial Dust Monitoring and Alerting.]

6.2.9.4 Microbial Air Contamination

[V2 6059] The system **shall** provide air in the habitable atmosphere that is microbiologically safe for human health and performance.

[Rationale: Microbiologically safe air is essential to prevent infection, allergic response, and mitigate risk to crew health and performance. Assessing microbiological safety of air relies primarily on the enumeration and identification of viable, medically significant microorganisms (bacteria and fungi) that are known to cause disease. Historically, atmospheric microbial concentrations in spacecraft habitable atmosphere have been controlled by maintaining a continuous flow of air through High Efficiency Particulate Air (HEPA) filters that remove at least 99.97% of airborne particles 0.3 µm in diameter, or larger. Medical significance of microorganisms and allowable levels of microorganisms are set based on guidance from the JSC Microbiology Laboratory. Program level requirements for atmospheric quality include considerations for factors such as vehicle architecture and mission duration. Considerations are to be taken for scenarios where there is a period of dormancy or uncrewed operations.]

6.3 Water

The challenges of providing quality water vary for different system designs and diverse water sources, e.g., recycled humidity condensate and ground-supplied water. In the design process, early identification of potential water quality impacts enables mitigation by design. Water quality monitoring through the use of in-flight and preflight analysis techniques are essential tools for use in verifying water quality, evaluating trends, and documenting potential exposures.

6.3.1 Water Quality and Monitoring

6.3.1.1 Potable Water Quality

[V2 6026] At the point of crew consumption or contact, the system **shall** provide aesthetically acceptable potable water that is chemically and microbiologically safe for human use, including drinking, food rehydration, personal hygiene, and medical needs.

[Rationale: Point of crew consumption or contact refers to the location from which potable water is dispensed for use in drinks, food rehydration, personal hygiene, and medical needs and any potential in-flight maintenance sites. Safe water pollutant levels have been established for certain prioritized compounds specifically for human-rated space vehicles by the JSC Toxicology and Environmental Chemistry Laboratory in cooperation with a subcommittee of the National Research Council Committee on Toxicology; however, the current list in JSC-63414, Spacecraft Water Exposure Guidelines (SWEGs), is not all inclusive, and other compounds may be of concern. For these other compounds, the United States Environmental Protection Agency maximum contaminant levels can be utilized as conservative screening limits. (For additional guidance, reference chapter 6, Natural and Induced Environments, in the HIDH.) To determine which contaminants are present, a complete chemical characterization of potential water sources is to be performed. Evaluation of aesthetic properties is important to ensure that the potable water does not have an adverse odor or taste such that it would cause crewmembers to diminish consumption and increase the risk of underhydration or dehydration of the crewmember. Aesthetic acceptability can either be assessed qualitatively by an evaluation panel or indirectly through compliance with the applicable water quality requirements.

Special consideration should be taken with treatment chemicals and residual biocides. For example, at effective biocidal levels iodine can alter the aesthetics of the water as well as cause iodine-related illness; refer to Section 6.3 of the HIDH, NASA/SP-2010-3407. Allowable concentrations for other treatment chemicals and biocides can be found in JSC-63414 and United States Environmental Protection Agency guidelines.

Microbially safe water is essential to prevent infection and mitigate risk to crew health and performance. Microbiological assessment of water safety relies primarily on the identification of viable, medically significant microorganisms (bacteria, fungi, and parasitic protozoa) that are known to cause disease. Monitoring targets have included specific categories of microorganisms (e.g., coliform bacteria) that indicate that the water may have been contaminated or not adequately treated. Microbial enumeration of potable water has also been used historically as an indicator of overall system performance. Previous space flight missions have used a combination of these monitoring approaches in combination with mitigation strategies to confirm the safety of potable water. Medical significance of microorganisms and allowable levels of microorganisms are set based on guidance from the JSC Microbiology Laboratory. Program level requirements for water quality include considerations for factors such as water source, vehicle architecture, and mission duration.]

[V2 6027] Requirement merged into [V2 6026].

6.3.1.3 Water Contamination Control

[V2 6051] The system **shall** prevent potable and hygiene water supply contamination from microbial, atmospheric (including dust), chemical, and non-potable water sources to ensure that potable and hygiene water are provided.

[Rationale: While ensuring the delivery of potable water to crew on orbit is important, contamination from sources within the delivery system or from the environment is also possible.]

6.3.1.4 Water Quality Monitoring

[V2 6046] Water quality monitoring capability **shall** include preflight, in-flight, and post landing sampling and analysis.

[Rationale: On-orbit water quality is critical to the health of the crew. Rigorous ground processing with preflight water sampling and contamination assessment prevents in-flight water quality problems and thus minimizes the need for in-flight contamination monitoring and remediation of any water quality parameters that are out of specification. In-flight sampling capability supports real-time contaminant monitoring and remediation of stored or regenerated water systems as needed for long-duration missions. Ground-based quality analyses of in-flight and post landing samples provide a record of crew exposures and are used to determine follow-on ground processing steps.]

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[V2 6105] Requirement merged into [V2 6026].

6.3.2 Water Quantity

[V2 6109] The system **shall** provide a minimum water quantity as specified in Table 4, Water Quantities and Temperatures, for the expected needs of each mission, which should be considered mutually independent.

[Rationale: To maintain crewmember hydration status and allow crewmembers to perform duties nominally, adequate water intake is needed, which is a culmination of drinking water, dietary intake from food and drinks, as well as fluid loading and recovery needs. Proper hydration contributes to adequate urine output to clear metabolic wastes and to account for perspiratory and other insensible losses. Dehydration of the crewmember will have consequences ranging from poor communication and crewmember performance caused by dry mucous membranes, nosebleeds, headache, malaise, and fitful sleep to urinary tract infection or urinary calculi if the under-hydration state is continued. Dehydration also cancels many of the thermal benefits of heat acclimatization and aerobic fitness. Potable water is also necessary during suited operations to prevent dehydration related to perspiration and insensible water loss, as well as to improve comfort.

For fluid loading, 1.5 L of water per crewmember is based on the Space Shuttle and the Commercial Crew Program (CCP) prescriptions for reentry fluid loading. Table 4 calls out a minimum of 1 L (33.8 fl oz) of water per crewmember, and an additional 500 mL (16.9 fl oz) will be available per crewmember from their unused daily water allocation. Vehicles that may wave off prior to reentry need to protect for two fluid loadings per crewmember. Fluid loading is based on crewmember weight and requires the use of salt tablets in addition to water, unless an alternative solution is used. Without fluid loading, the crew is more likely to experience orthostatic intolerance (passing out when standing) during and after deorbit.

Of note, the water required during the post landing phase, for up to about 36 hours, is to ensure crewmembers are properly hydrated. Less water may be needed for hydration following a launch abort, since crewmembers will not have undergone space flight fluid loss. Additionally, for missions longer than a few days, hot and cold food and beverages provide an important psychological benefit. The amount of hot and cold water to be provided depends on the number of crew, mission length, and types of food and beverage available. To ensure the crew have adequate hydration, the Potable Water for Hydration minimum amount per day is available for drinking, and for rehydrating foods/drinks. This value does not change with removal of rehydratable foods or addition of thermostabilized food as the minimum amount is based on the physiological needs and not how it is consumed.

Water is also needed for personal hygiene, which will depend on the mission length, number of crewmembers, and design of the hygiene system. Clean water is necessary for maintaining skin, hair, and dental health of the crew. Water may not be required for some hygiene activities where alternatives, e.g., rinseless shampoo, pre-wetted towels, are provided. Water for medical contingency use is required for many situations, including wound irrigation during the various activities of a mission, which is based on experience and data from Shuttle, ISS, and Apollo programs. The amount of contingency water will be determined on the expected events to occur and frequency of events. Eye wash capability for particulate events is expected, especially for lunar and planetary missions, as there is an increased risk of exposure to dust and regolith on the lunar or other planetary surfaces. Some medical situations require large quantities of water, for example, LiOH or other toxic substances in the eye or skin, or in a wound. However, these events are off-nominal and occur at lower frequency during the mission than particulate events and may be considered contingencies. The quantity of water to be provided depends on the number of crewmembers, duration of mission, and expected contingency events and should ensure that medical treatment can be provided.

Additional considerations for water quantities should include sampling needs for routine water testing and monitoring, as well as any agricultural or hydroponic systems that would be in addition to the crew needs for hydration. All quantities should be considered mutually independent. Water quantities provided are not limited to only what is replenished with the arrival of cargo or crew vehicles and can be obtained by other means, include that of recycling.]

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[V2 6029] Requirement merged into [V2 6109].

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[V2 6030] Requirement merged into [V2 6109].

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[V2 6037] Requirement merged into [V2 6109].

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[V2 6038] Requirement merged into [V2 6109].

6.3.3 Water Temperature

[V2 6110] The system **shall** provide the appropriate water temperature as specified in Table 4, Water Quantities and Temperatures, for the expected needs of each mission and task.

[Rationale: Over the course of long-duration missions, crewmembers can tire of repetitive beverages and foods. Providing hot and cold water is an important way of keeping the crewmembers interested in their meals and providing a familiar contact to normal Earth living, as well as making the food items more acceptable and palatable. Additionally, the use of higher water temperatures allows for faster rehydration of beverages and foods, as well as aiding in the prevention of microbial growth.

Additionally, providing proper temperature of the hygiene and medically used waters will support comfortable body cleansing and preventing thermal injury to the tissue, especially when performing irrigations. Terrestrially, building code for typical shower valves is to limit the outlet temperature to 120F (48.9C), which is at the tissue damage limit. Note that the average ISS Potable Water Dispenser (PWD) hot water is 180°F (~82°C) but can vary from 150-200°F (~65-93°C). Crewmembers are trained to use a combination of Ambient and Hot to get the desired temp for hygiene.]

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[V2 6041] Requirement merged into [V2 6110].

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[V2 6042] Requirement merged into [V2 6110].

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[V2 6043] Requirement merged into [V2 6110].

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[V2 6044] Requirement merged into [V2 6110].

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[V2 6045] Requirement merged into [V2 6110].

Table 4—Water Quantities and Temperatures

Requirement	Quantity (quantities are mutually independent)	Temperature		
		Hot	Nominal	Cold
Potable Water for Hydration††	Minimum 2.5 L (84.5 fl oz) per crewmember per day *(allocation to include 600 mL per meal per crewmember to be available as Hot Water)*	between 68ºC (155ºF) and 79ºC (175ºF)**	between 18ºC (64ºF) and 27ºC (81ºF)	maximum temperature of 16ºC (60ºF)
Potable Water Quantity for Personal Hygiene	Minimum 400 mL (13.5 fl. oz.) per crewmember per day	between 29ºC (85ºF) and 46ºC (115ºF)		
Potable Water Quantity for Eye Irrigation	Minimum 500 mL (16.9 fl oz) per crewmember	between 18ºC (64ºF) and 27ºC (81ºF)		
Potable Water for Medical Use and Medical Contingency	Minimum of 5 L (169.1 fl oz) per event			
Potable Water for EVA Operations	Minimum 240 mL (8.1 fl oz) per crewmember per EVA hour	between 68ºC (155ºF) and 79ºC (175ºF)	between 18ºC (64ºF) and 27ºC (81ºF)	maximum temperature of 16ºC (60ºF)
Potable Water for Fluid Loading for Reentry from Microgravity to Partial or Earth Gravity	Minimum of 1 L (33.8 fl oz) per crewmember*			
Potable Water for Crew Recovery During Entire Recovery Period	Minimum of 1 L (33.8 fl oz) per crewmember for every 8-hour period			
Sampling Water Quantity	Mission dependent***	N/A		
Agriculture Water Quantity	Mission dependent***	TBD		

** Vehicles that may wave-off prior to reentry are to protect for this quantity of water for fluid loading for each of two deorbit attempts.*
*** Critical for missions longer than three days.*
**** Mission dependent as sized by appropriate sampling or plant science personnel.*
†† The bulk supply of water should be accessible as ambient and/or cold.

6.3.4 Water Dispensing

6.3.4.1 Potable Water Dispensing Rate

[V2 6039] Water **shall** be dispensed at a rate that is compatible with the food system.

[Rationale: A water dispensing rate is to be defined as a rate that is compatible with the food packaging and time demands of the allotted meal schedule to ensure that the crew is able to

prepare for and perform tasks, e.g., filling drink bags and/or rehydrating food in a reasonable amount of time. The rate will depend on the design of the food system and the amount of water required, if necessary, to rehydrate beverages and food. The program will define appropriate increments in accordance with HMTA. This rate is not intended to require an additional water quantity beyond that required for nominal mission water usage. It needs to be compatible with the increments. For example, a rate of 500 mL/minute (16.9 oz/minute) can ensure timely food preparation when rehydration is needed for multiple meals or drinks for all crewmembers and meals.]

6.3.4.2 Potable Water Dispensing Increments

[V2 6040] To prevent overflow, water **shall** be dispensable in specified increments that are compatible with the food preparation instructions and time demands of the allotted meal schedule.

[Rationale: Water dispensing increments are to be defined to properly hydrate food and beverages. In addition, palatability is to be included as part of the assessment when determining the proper hydration of food and beverages. On ISS today, water is dispensed at 25 mL (milliliter) increments. All food portions are sized to be compatible with this increment (i.e., 25 mL to 250 mL). The increment was different in previous missions, as low as 15 mL. The program will define appropriate increments in accordance with HMTA.]

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[V2 6046] Requirement moved to section 6.3.1.

6.4 Environmental Hazards

The system interior atmosphere, water, or surfaces can become contaminated from multiple in-flight sources during operations, including material offgassing, payloads, other vehicles, crew, and planetary environments. Accordingly, only those materials or substances that, if offgassed or released into the habitable volume, are not or will not form hazardous substances and would not threaten human health are to be used within the spacecraft.

6.4.1 Toxic Chemicals

6.4.1.1 Toxic Hazard Level Three

[V2 6047] The system **shall** use only chemicals that are Toxic Hazard Level Three or below, as defined in JSC-26895, Guidelines for Assessing the Toxic Hazard of Spacecraft Chemicals and Test Materials, in the habitable volume of the spacecraft.

[Rationale: Potential contamination assessed as Toxic Hazard Level Four cannot be cleaned up by the crew and pose a risk of permanent injury or death. As such, only materials that either pose limited risk to crew or can be contained and disposed of by an appropriate clean-up

procedure should be used in the habitable volume or in systems that may credibly be released into the habitable volume (i.e., thermal working fluids). Toxic Hazard Level ratings are assigned by JSC Toxicology based on information received per JSC-27472, Requirements for Submission of Data Needed for Toxicological Assessment of Chemicals and Biologicals to be Flown on Manned Spacecraft.]

6.4.1.2 Toxic Hazard Level Four

[V2 6048] The system **shall** prevent Toxic Hazard Level Four chemicals, as defined in JSC-26895, from entering the habitable volume of the spacecraft.

[Rationale: Potential contamination assessed as Toxic Hazard Level Four cannot be contained by crew and may cause appreciable effects on coordination, perception, and memory, long-term serious injury (e.g., cancer), or may result in internal tissue damage. Toxic Hazard Level ratings are assigned by JSC Toxicology based on information received per JSC-27472, Requirements for Submission of Data Needed for Toxicological Assessment of Chemicals.]

6.4.1.3 Chemical Decomposition

[V2 6049] The system **shall** use only chemicals that, if released into the habitable volume, do not decompose into hazardous compounds that would threaten health during any phase of operations.

[Rationale: Only a few compounds, such as fluorinated coolants, have been shown to decompose into hazardous compounds during nominal spacecraft Atmosphere Revitalization System (ARS) operation. These compounds could present a toxic threat if the amount of the compound involved is sufficient, the ARS temperature is adequate, and the product compound is hazardous. Halon is an example of such a chemical; if it is sufficiently heated during its normal use as a fire suppressant, it breaks down into highly toxic gaseous compounds.]

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[V2 6050] Requirement moved to section 6.2.9.

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[V2 6051] Requirement moved to section 6.3.1.

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[V2 6052] Requirement moved to section 6.2.9.

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[V2 6053] Requirement moved to section 6.2.9.

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[V2 6054] Requirement merged into [V2 6059].

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[V2 6055] Requirement merged into [V2 6059].

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[V2 6056] Requirement merged into [V2 7081].

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[V2 6057] Requirement merged into [V2 7081].

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[V2 6058] Requirement moved to section 7.11.5.

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[V2 6059] Requirement moved to section 6.2.9.

6.4.2 Cross-Contamination Prevention

6.4.2.1 Biological Payloads

[V2 6060] Biological payloads, as well as the associated operational procedures and supporting personal protective equipment, **shall** meet the criteria defined by the JSC Biosafety Review Board guidelines contained in JPR-1800.5, Biosafety Review Board Operations and Requirements.

[Rationale: Biohazardous agents, which include bacteria, fungi, protozoa, viruses, cell cultures, and recombinant deoxyribonucleic acid (DNA), may be infectious and result in disease or contamination of water and food supplies or the internal environment. Payloads that contain biohazardous materials are to ensure that these materials are properly contained, handled, and discarded. JPR-1800.5 establishes requirements for the identification and assessment of biohazardous materials used in payload or ground-based experiments.]

6.4.2.2 Environment Cross-Contamination

[V2 6061] The system **shall** provide controls to prevent or otherwise minimize (as appropriate) biological cross-contamination between crew, payloads and vehicles to acceptable levels in accordance with the biosafety levels (BSL) defined in JPR-1800.5, as well between crew, payloads, vehicles and extraterrestrial planetary environments with the extent of application specific to individual planetary bodies and special locations thereon.

[Rationale: Biological contamination from crew, payloads (e.g., animals, plants, microorganisms), vehicle systems, waste, suits, spacecraft vehicle and planetary environments can negatively affect crew health, performance of the vehicle and its systems, the collection and integrity of scientific data (including the potential detection of microbial life forms). Additionally, biological contamination may risk planetary protection of the Earth via back-contamination upon return. Planetary protection categories and guidance to determine the applicability and extent of planetary protection measures for extraterrestrial environments as well as for return to Earth are documented in NPD 8020.7, Biological Contamination Control for Outbound and Inbound Planetary Spacecraft, and NID 8715.129 (or superseding documents) for the Moon and Mars. These documents are founded on, and consistent with the Committee for Space Research (COSPAR) Policy for Planetary Protection, an accepted approach for complying with the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (UN, 1967), Article IX.]

6.4.3 Availability of Environmental Hazards Information

[V2 6062] The system **shall** provide toxicological and environmental hazard information in formats accessible by the crew throughout the mission.

[Rationale: In case of accidental contact with hazardous materials during a mission, crew access to hazard information, e.g., Safety Data Sheets (SDSs), is necessary to determine methods of cleanup and exposure treatment.]

6.4.4 Contamination Cleanup

[V2 6063] The system **shall** provide a means to remove or isolate released chemical and biological contaminants and to return the environment to a safe condition.

[Rationale: In the event of a contamination event, contaminants are to be removed, isolated, or reduced from the environment to ensure the crew's health and ability to continue the mission. In some cases, such as a spill, vehicle systems may be unable to remove the contaminant; and the crewmembers will have to perform the cleanup themselves. Cleanup of a contamination includes the control and disposition of the contamination.]

6.5 Acceleration and Dynamic Loads

Exceeding acceleration limits can significantly impair human performance and cause injury, thereby threatening mission success and crew survival.

For mission durations > 30 days, the crew is considered deconditioned. For mission durations ≤ 30 days, the crew is considered non-deconditioned. Emergency conditions refer to off-nominal *conditions within first 30 days of Earth launch where crew survival is prioritized (e.g. launch aborts, emergency entry).*

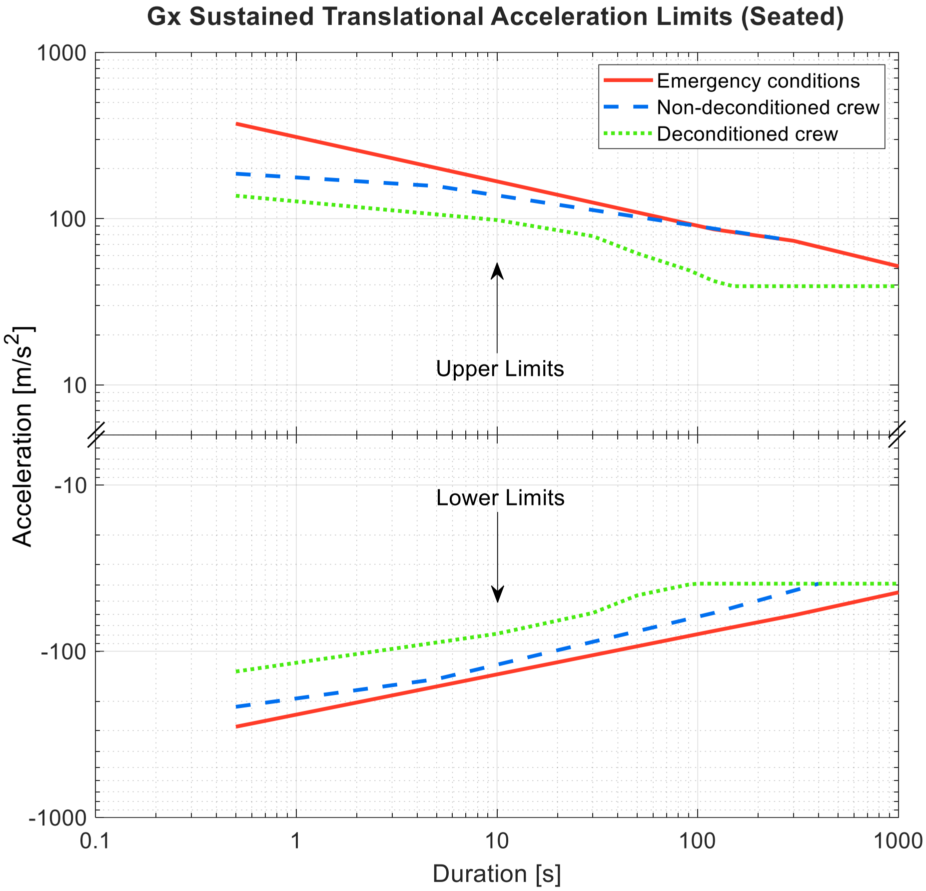
6.5.1 Sustained Translational Acceleration Limits

[V2 6064] The system **shall** limit the magnitude, direction, and duration of crew exposure to sustained (>0.5 seconds) translational acceleration by staying below the limits in Figure 4, Gx Sustained Translational Acceleration Limits (Seated), Figure 5, Gy Sustained Translational Acceleration Limits (Seated), and Figure 6, Gz Sustained Translational Acceleration Limits (Seated) for seated posture, and Figure 7, Gx Sustained Translational Acceleration Limits (Standing), Figure 8, Gy Sustained Translational Acceleration Limits (Standing), and Figure 9, Gz Sustained Translational Acceleration Limits (Standing) for standing posture.

[Rationale: The limits in these figures represent safe levels of sustained translational acceleration under nominal and off-nominal conditions. Exposure to acceleration above these limits could significantly affect human performance for maneuvering and interacting with a spacecraft. A separate limit was defined for deconditioned crew because crewmembers are expected to have capabilities due to deconditioning from exposure to reduced gravity. For the extreme conditions of a launch abort or emergency entry, limits are higher because it may be necessary to expose the crew to accelerations more severe than those experienced nominally. Humans are never to be exposed to translational acceleration rates greater than these elevated limits, as this significantly increases the risk of incapacitation, thereby threatening crew survival. The acceleration vectors are relative to the "axis" of the upper body, particularly with a focus on a line running from the eye to the heart with the neck in a neutral posture. However, the acceleration limit charts do not account for all body types or temporary off-axis accelerations or body positions. Each axis is to be analyzed separately, and conservatism in the limits for each axis covers any cumulative effect of acceleration in multiple axes.

All limits further assume adequate restraint(s) are provided for all body postures during the period of sustained loading. Adequate restraint for the purposes of Linear Sustained Acceleration Limits are defined as devices sufficient to arrest motion between the occupant and vehicle interior by applying counterforce. Restraints must also prevent unintended contact between the crewmember and the interior of the vehicle within the linear sustained acceleration limits described herein, while facilitating continual access to and operation of vehicle displays and controls. All limits also assume the crew is wearing a counterpressure garment intended to mitigate the effects of orthostatic intolerance.

For applying the standing limits refer to NASA/TM-20205008196 Artemis Sustained Translational Acceleration Limits: Human Tolerance Evidence from Apollo to International Space Station.]



Acceleration limits for emergency conditions (seated)

Upper limit	Duration [s]	0.5	120	300	1200
	Acceleration [m/s²]	373	86.3	73.5	49.0
Lower limit	Duration [s]	0.5	120	300	1200
	Acceleration [m/s²]	-284	-75.5	-60.8	-42.2

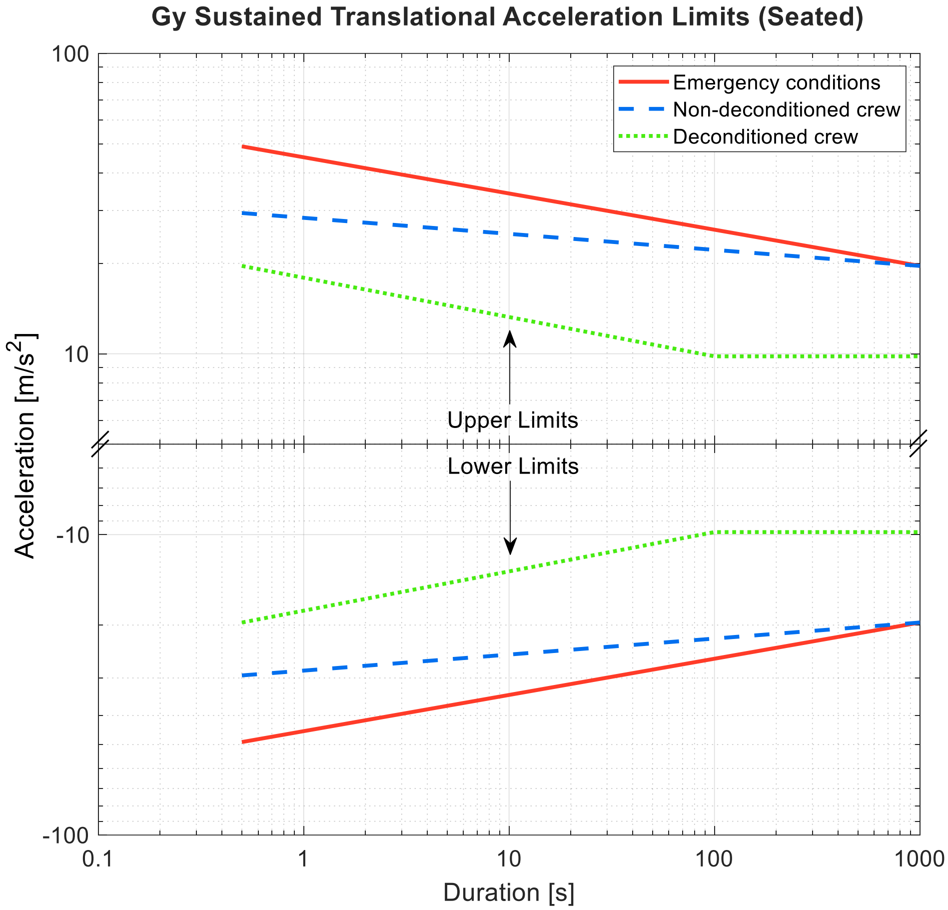
Acceleration limits for non-deconditioned crew (seated)

Upper limit	Duration [s]	0.5	5	300	
	Acceleration [m/s²]	186	157	73.5	
Lower limit	Duration [s]	0.5	5	120	400
	Acceleration [m/s²]	-216	-147	-58.8	-39.2

Acceleration limits for deconditioned crew (seated)

Upper limit	Duration [s]	0.5	10	30	50	90	120	150	10000
	Acceleration [m/s²]	137	98.1	78.5	61.8	49.0	42.2	39.2	39.2
Lower limit	Duration [s]	0.5	10	30	50	90	100	10000	
	Acceleration [m/s²]	-132	-78.5	-58.8	-46.1	-39.7	-39.2	-39.2	

Figure 4—Gx Sustained Translational Acceleration Limits (Seated)



Acceleration limits for emergency conditions (seated)

Upper limit	Duration [s]	0.5	1000	1000
	Acceleration [m/s^2]	49.0	19.6	19.6
Lower limit	Duration [s]	0.5	1000	1000
	Acceleration [m/s^2]	-49.0	-19.6	-19.6

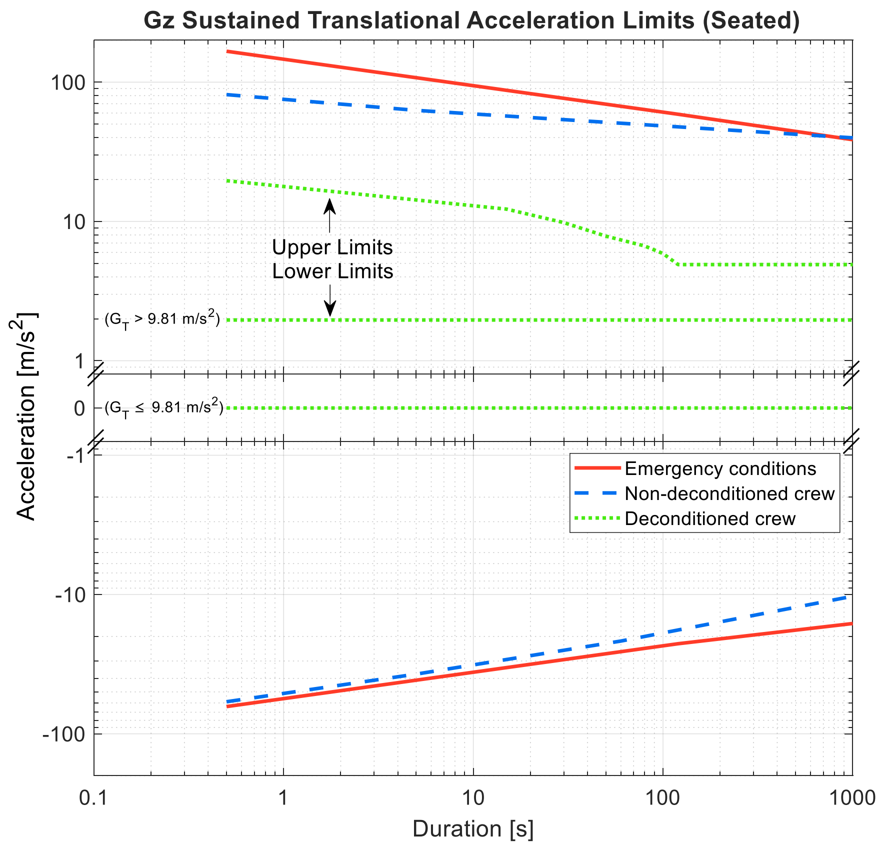
Acceleration limits for non-deconditioned crew (seated)

Upper limit	Duration [s]	0.5	1000	1000
	Acceleration [m/s^2]	29.4	19.6	19.6
Lower limit	Duration [s]	0.5	1000	1000
	Acceleration [m/s^2]	-29.4	-19.6	-19.6

Acceleration limits for deconditioned crew (seated)

Upper limit	Duration [s]	0.5	100	10000
	Acceleration [m/s^2]	19.6	9.81	9.81
Lower limit	Duration [s]	0.5	100	10000
	Acceleration [m/s^2]	-19.6	-9.81	-9.81

Figure 5—Gy Sustained Translational Acceleration Limits (Seated)



Acceleration limits for emergency conditions (seated)

Upper limit	Duration [s]	0.5	120	1200
	Acceleration [m/s^2]	167	58.8	37.3
Lower limit	Duration [s]	0.5	120	1200
	Acceleration [m/s^2]	-63.7	-22.6	-15.7

Acceleration limits for non-deconditioned crew (seated)

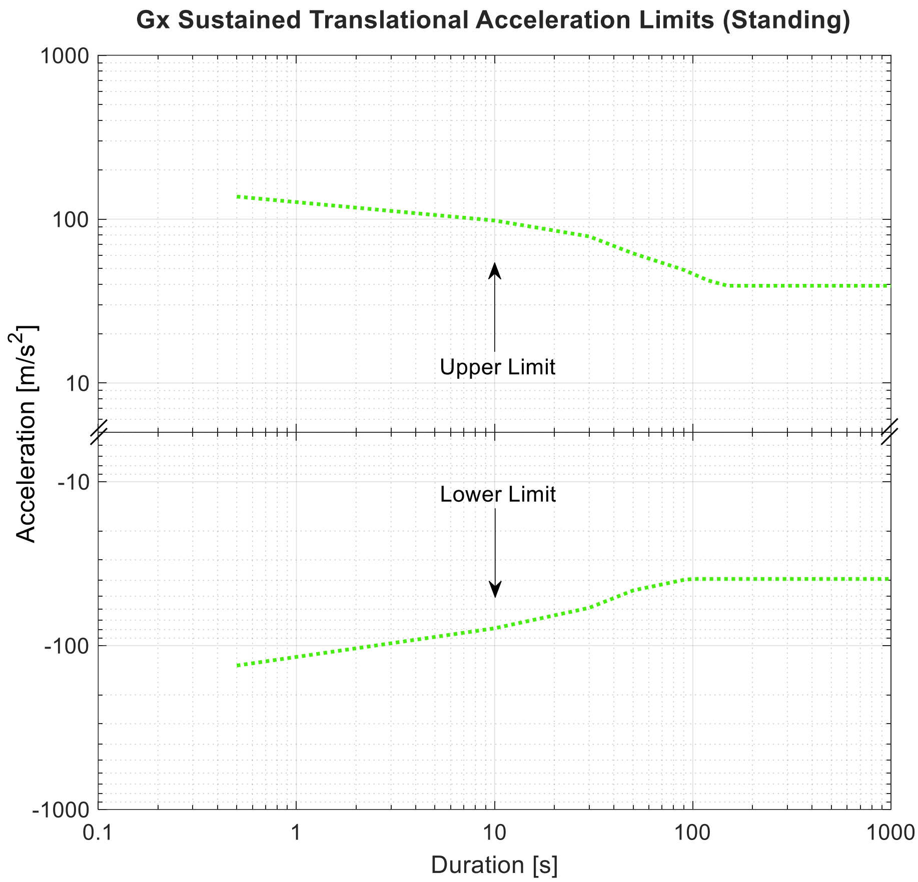
Upper limit	Duration [s]	0.5	5	1200	
	Acceleration [m/s^2]	81.4	62.8	39.2	
Lower limit	Duration [s]	0.5	5	60	1200
	Acceleration [m/s^2]	-58.8	-37.3	-21.6	-9.81

Acceleration limits for deconditioned crew (seated)

Upper limit	Duration [s]	0.5	15	30	50	80	100	120	1000
	Acceleration [m/s^2]	19.6	12.3	9.81	7.85	6.67	5.88	4.90	4.90
Lower limit	Duration [s]	0.5	1000						
	Acceleration ($G_T < 9.81$ m/s^2) [m/s^2] *	0	0						
	Acceleration ($G_T \geq 9.81$ m/s^2) [m/s^2] *	1.96	1.96						

* The lower G_z acceleration limit is 0 m/s^2 from Entry Interface until the total Linear Reaction G_T reaches 9.81 m/s^2, then the limit is 2 m/s^2, where $G_T = \sqrt{{G_x}^2 + {G_y}^2 + {G_z}^2}$.

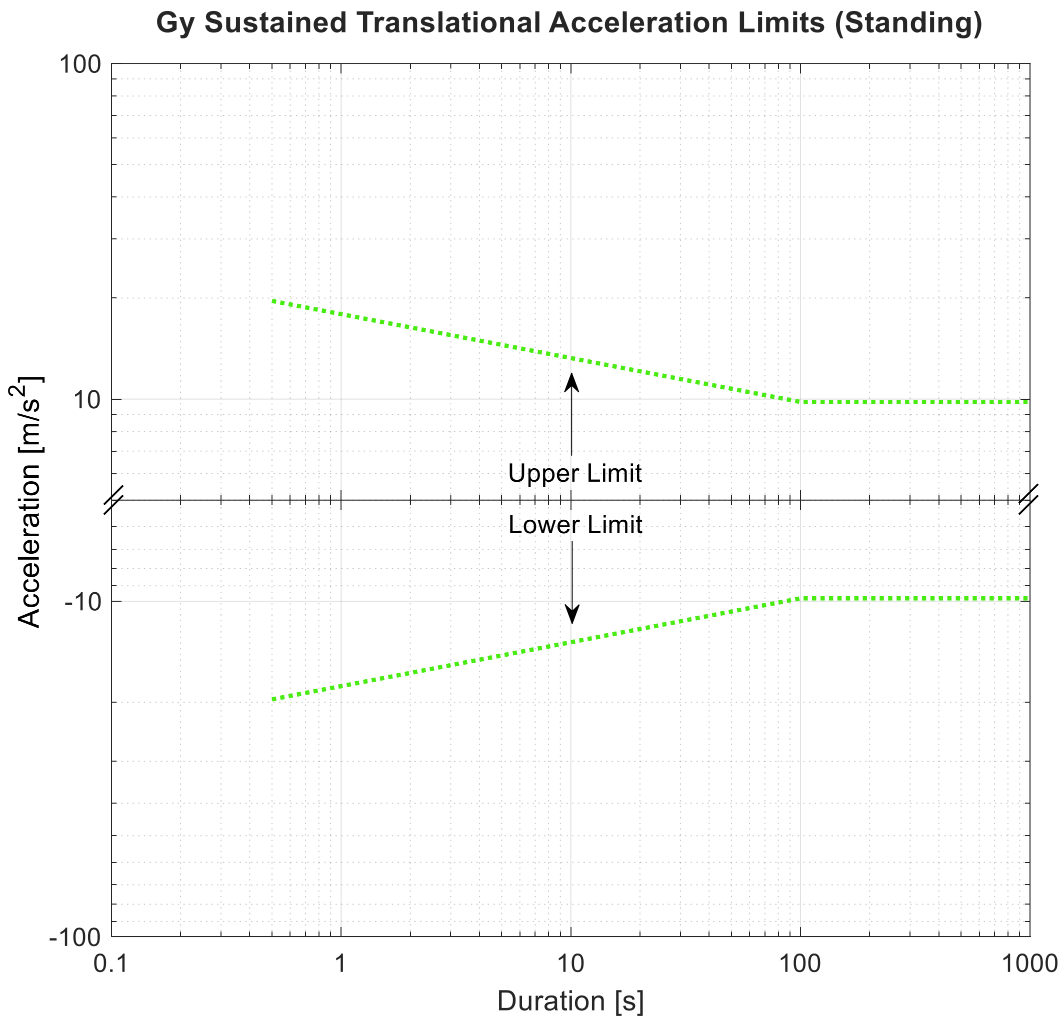
Figure 6—Gz Sustained Translational Acceleration Limits (Seated)



Acceleration limits for deconditioned crew (standing)

Upper limit	Duration [s]	0.5	10	30	50	90	120	150	10000
	Acceleration [m/s^2]	137	98.1	78.5	61.8	49.0	42.2	39.2	39.2
Lower limit	Duration [s]	0.5	10	30	50	90	100	10000	
	Acceleration [m/s^2]	-132	-78.5	-58.8	-46.1	-39.7	-39.2	-39.2	

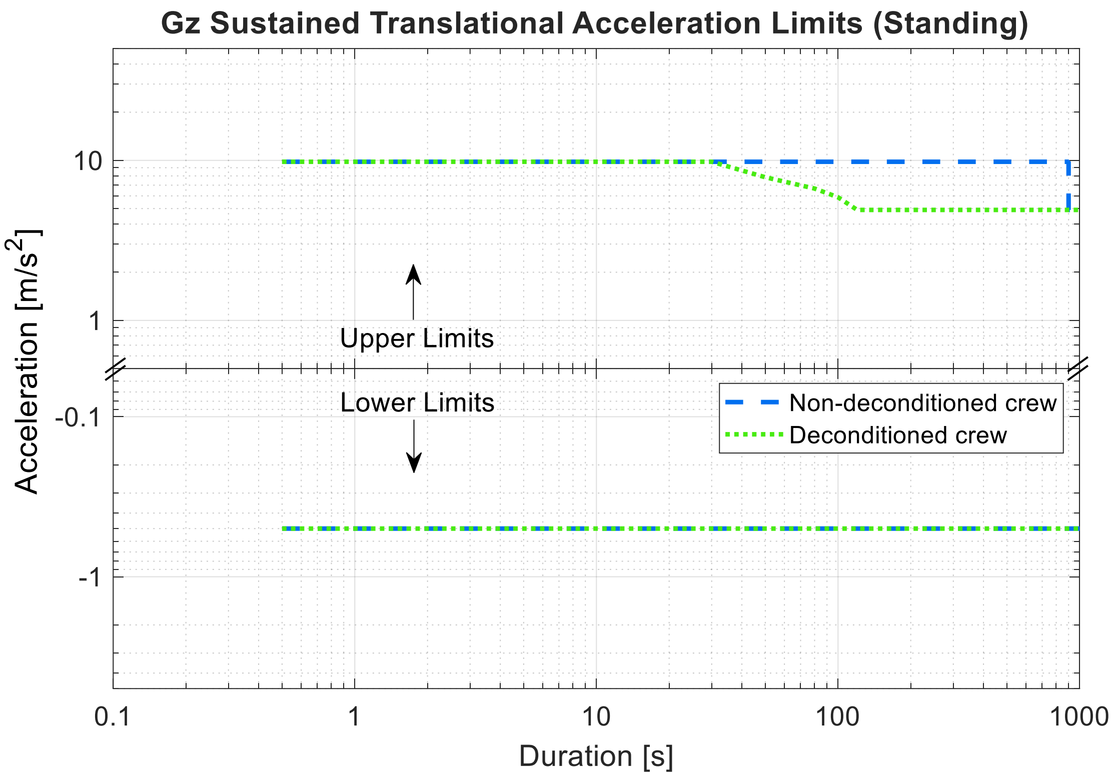
Figure 7—Gx Sustained Translational Acceleration Limits (Standing)



Acceleration limits for deconditioned crew (standing)

Upper limit	Duration [s]	0.5	100	10000
	Acceleration [m/s^2]	19.6	9.81	9.81
Lower limit	Duration [s]	0.5	100	10000
	Acceleration [m/s^2]	-19.6	-9.81	-9.81

Figure 8—Gy Sustained Translational Acceleration Limits (Standing)



Acceleration limits for non-deconditioned crew (standing)

Upper limit	Duration [s]	0.5	0.5 < t < 900	900	Sustained
	Acceleration [m/s^2]	9.81	9.81	4.90	4.90
Lower limit	Duration [s]	0.5	Sustained		
	Acceleration [m/s^2]	-0.5	-0.5		

Acceleration limits for deconditioned crew (standing)

Upper limit	Duration [s]	0.5	30	50	80	100	120	Sustained
	Acceleration [m/s^2]	9.81	9.81	7.85	6.67	5.88	4.90	4.90
Lower limit	Duration [s]	0.5	Sustained					
	Acceleration [m/s^2]	-0.5	-0.5					

Figure 9—Gz Sustained Translational Acceleration Limits (Standing)

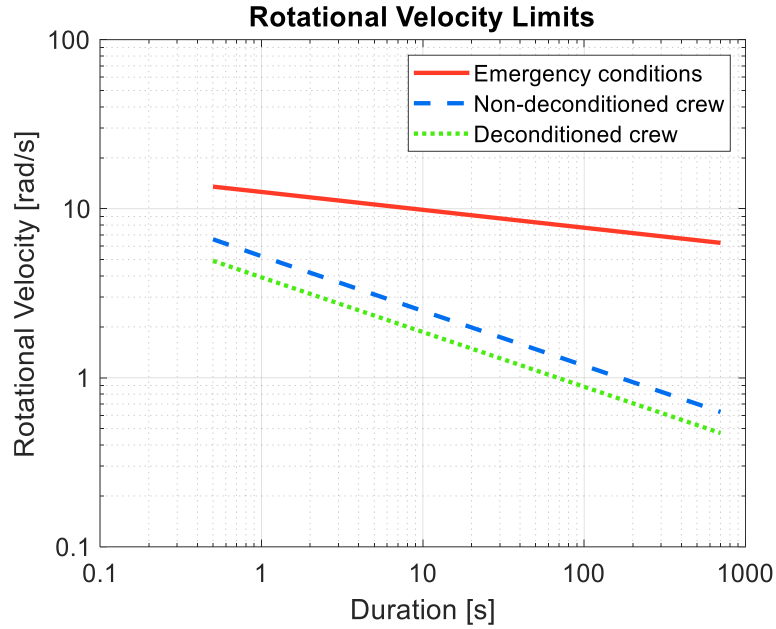
6.5.2 Rotation Limits

6.5.2.1 Rotational Velocity

[V2 6065] The system **shall** limit crew exposure to rotational velocities in yaw, pitch, and roll by staying below the limits specified in Figure 9, Rotational Velocity Limits.

[Rationale: The limits in this figure represent safe levels of sustained rotational acceleration for crewmembers under nominal and off-nominal conditions. Exposure to rotational acceleration above these limits could significantly affect human performance for maneuvering and interacting with a spacecraft. The limits for deconditioned crewmembers are lower because crewmembers

are expected to have degraded capabilities due to deconditioning from exposure to reduced gravity. For emergency conditions, limits are higher because it may be necessary to expose the crew to accelerations more severe than those experienced nominally. Humans are never to be exposed to rotational acceleration rates greater than these elevated limits as this significantly increases the risk of incapacitation, thereby threatening crew survival.]



Data for Curves

Emergency conditions	Duration [s]	0.5	1	700
	Rotational Velocity [rad/s]	14	13	6.3
Non-deconditioned crew	Duration [s]	0.5	1	700
	Rotational Velocity [rad/s]	6.6	5.2	0.63
Deconditioned crew	Duration [s]	0.5	1	700
	Rotational Velocity [rad/s]	4.9	3.9	0.47

Figure 10—Rotational Velocity Limits

6.5.2.2 Sustained Rotational Acceleration Due to Cross-Coupled Rotation

[V2 6066] The system **shall** prevent the crew exposure to sustained (>0.5 second) rotational accelerations caused by cross-coupled rotations greater than 2 rad/s^2.

[Rationale: Crewmembers are not expected to be able to tolerate sustained cross-coupled rotational accelerations (simultaneous rotations about two different axes) in excess of 2 rad/s^2 without significant discomfort and disorientation. Sustained cross-coupled rotational accelerations exceeding this amount have been found to significantly impact human performance and autonomic function (e.g., nausea, dizziness, and disorientation; degradations in neurovestibular and sensorimotor performance, physical reach, and cognition), potentially for an extended period of time after exposure. Note that rotational acceleration due to cross-coupled rotation can be computed for rotational velocity components represented in any vehicle- or

head-referenced coordinate frame. Ideally, rotational velocities should be decomposed into their orthogonal principal components before computing the acceleration due to cross-product terms. For scientific references regarding this subject, see chapter 6, Natural and Induced Environments, of the HIDH.]

6.5.2.3 Transient Rotational Acceleration

[V2 6067] The system **shall** limit transient (≤0.5 seconds) rotational accelerations in yaw, pitch, or roll to which the crew is exposed and the limit used appropriately scaled for each crewmember size from the 50^{th} percentile male limits of 2,200 rad/s^2 for nominal and 3,800 rad/s^2 for off-nominal cases.

[Rationale: Crewmembers are not expected to be able to tolerate sustained rotational accelerations in excess of 2,200 rad/s2 for nominal and 3,800 rad/s2 for off nominal cases. This could occur as a result of an impact, whereby brief, high-magnitude rotational accelerations are imparted to the crew. These values relate to a risk of 5% or 19% risk of brain injury, respectively, for a 50th percentile male. These values should be appropriately scaled to other crewmember sizes as needed. For additional information scaling these limits, see Petitjean, A., et al. (2015). Normalization and Scaling for Human Response Corridors and Development of Injury Risk Curves. Accidental Injury: Biomechanics and Prevention. N. Yoganadan, A. Nahum and J. Melvin. New York, Springer Science+Business Media: 769-792.]

Deleted:

[V2 6068] Requirement deleted.

6.5.3 Acceleration Injury Prevention

[V2 6069] The system **shall** mitigate the risk of injury to crewmembers caused by accelerations during dynamic mission phases per Table 5, Acceptable Injury Risk Due to Dynamic Loads.

[Rationale: During dynamic flight phases, there is potential for impact and flail injury, which includes crewmember extremities impacting vehicular surfaces or objects, hyperextending, hyperflexing, hyper-rotating, fracturing, or dislocating if proper restraints and supports are not used. Features such as harnesses, form-fitting seats, and tethers may help maintain the proper position of the crewmember's body and limbs to reduce movement or contact with vehicle surfaces that would produce injury. In addition, the design of spacesuits may contribute to reducing injury to the crew. Preventing the inadvertent contact of extremities with vehicular structure or interior components significantly reduces the likelihood of limb fracture or soft tissue injury during a dynamic flight event. Extremity guards, tethers, garters, and handholds have been used to reduce injury in other spacecraft, aircraft, and automotive vehicles. Injury classifications are based on the Operationally Relevant Injury Scale defined in NASA/TP-2015-218578, Final NASA Panel Recommendations for Definition of Acceptable Risk of Injury Due to Space Flight Dynamic Events. Occurrence of dynamic cases identified in Table 5 are based on statistical modeling of possible dynamic events. See NASA/TP-2015-218578 for more

information. For example, during the reentry of Space Transportation System (STS)-107, the crew had notable flail injuries in their extremities, upper body, and head from the dynamic accelerations and motions that were determined to be a lethal event. Contributing factors to this involved both inertial reels from the seat belts and the helmet when the crew were exposed to cyclical motions. The seat belt inertial reel mechanisms failed, which resulted in crew body flail. The helmets did not conform to crew head, which resulted in lethal head injuries when exposed to cyclical forces.]

Table 5—Acceptable Injury Risk Due to Dynamic Loads

Injury Severity (Class)*	≥95% of dynamic cases	<5% of dynamic cases
Minor (I)	<4%	<23%
Moderate (II)	<1%	<4%
Severe (III)	<0.1%	<0.7% [<1%]□
Life-Threatening/Fatal (IV)	<0.1%	<0.7%

*Injury classes are defined in NASA/TP-2015-218578.
□Acceptance of higher occurrence in brackets assumes Search and Rescue forces are able to access crewmembers within 30 minutes of mishap occurrence.

6.5.4 Injury Risk Criterion

[V2 6070] The system **shall** limit crew exposure to transient translational acceleration (≤0.5 seconds) by limiting the injury risk criterion (β/beta) to no greater than 1.0 (Low) for seated or standing crew as defined by Dynamic Response (DR) limits in NASA/TM-20205008198 Table 2 “Updated Dynamic Response Limits for Standing”, while crew are restrained as required in NASA/TM-2013-217380REV1 for seated crew, or NASA/TM – 20205008198 for standing crew.

[Rationale: The Brinkley Dynamic Response model will provide an injury risk assessment during dynamic phases of flight for accelerations <0.5 second. Application of this model assumes that a crewmember will be similarly restrained during all events where the Brinkley model is applied. Human tolerance for injury risk limits for development of space vehicles that are based on human volunteer impact test data and operational emergency escape system experience such as the Brinkley criterion have been adjusted for landing impact after reentry considering existing knowledge of the physical and physiological deconditioning related to long-term exposure to the microgravity of space. The vast experience in human testing of aircraft ejection seats and operational experience with emergency escape systems have enabled the highest fidelity for injury prediction, using the Brinkley model in the G_z axis. Although the maximum allowable Brinkley β value is 1.0 for any given level of risk, the vehicle occupant protection system design is to strive to achieve β values as low as reasonably achievable for as many of the landing conditions and scenarios as possible. The criteria include dynamic response limits that have been established for varying probabilities of injury. This model may be used primarily for landing scenarios, but it is applicable for all dynamic phases of flight for accelerations less than 0.5 second. Application of the Brinkley Dynamic Response model is described in NASA/TM-2013-217380REV1. Structural failure may present an occupant protection hazard through impinging upon occupant volume in such a way as to injure crewmembers.

The threshold for what constitutes standing posture is less than 80% of the total +Gz axis force being transmitted through the crewmember's buttock and thighs. Crewmembers in a standing posture without the protections offered by a seat or similar support structure will have lower tolerance to transient acceleration. Lower acceleration limits have been established to account for the risk of injury to the lower extremities. For transient accelerations occurring more than 30 days mission elapsed time, a lower limit is specified to account for space flight deconditioning effects on injury tolerance. These additional limits assume additional equipment mass, such as the spacesuit, borne by the crewmember is less than 20% of the crewmember's shirtsleeve mass. They also assume sufficient extremity and torso restraints to prevent flail and motion that could result in further injury not accounted for by the reduced limits. It is assumed that the primary direction of loading will be in +G_Z direction for the standing posture, and that the crewmember will remain in an upright orientation during the dynamic event, as it assumed the load would be primarily in the +Gz direction. The limits specified in NASA/TM-20205008198, Table 2 "Updated Dynamic Response Limits for Standing" are only valid if the restraint configuration prevents the crewmember from losing balance during the dynamic event.]

6.5.5 Dynamic Mission Phases Monitoring and Analysis

[V2 6111] The system **shall** collect vehicle and crewmember acceleration parameters, specific kinematic responses, and associated metadata, during all dynamic mission phases and suited operations (defined as ascent, abort, entry, descent, landing, post landing, and EVA operations) to correlate with any injuries incurred by crewmembers.

[Rationale: Systems are to be capable of monitoring the vehicle and crewmember-specific acceleration levels and associated crewmember kinematic responses (e.g., in-cabin video, crewmember-worn accelerometry, suit instrumentation during dynamic mission phases to correlate with any crewmember injuries. This assessment is critical to understanding the loads imparted to the human to: 1) aid in the assessment of any injuries incurred; 2) predict and correct harmful conditions before they occur; and 3) identify appropriate design changes to minimize injuries on future flights/vehicles. This data is also critical to inform modeling and analysis capabilities for future vehicles. The collection of associated metadata will enable mitigation of risks associated with dynamic mission phases, including the ability of the crew to egress during off-nominal events. Such metadata may include, but is not limited to: Vehicle-related data such as vehicle position at landing (upright/side-lying/inverted), cabin temperature and humidity, duration of crew egress from the vehicle, and any anomalies that occurred during the dynamic phase (e.g. toxin leaks, hardware/software failures, etc.); environmental data such as wave height for water landings, time of day, and weather conditions; and physiological data such as percentage of crew with nausea/vomiting, crew fatigue and fitness level, crew postlanding task performance data, and any injuries or close-calls. Accelerometers and other sensors can be located in the suit, in the seat, or elsewhere in the vehicle.]

6.5.6 Hang Time Limit

[V2 6112] The system **shall** limit crew exposure to suspension trauma conditions to seven minutes or less.

[Rationale: The hang time tolerance limit of seven minutes was chosen to protect the crew from a variety of life-threatening post landing complications when their vehicle lands in an inverted posture. This time limit reduces the probability the crew will experience suspension trauma symptoms. Suspension trauma, or harness hang syndrome, is the closest comparable terrestrial condition to the crew hanging in an inverted seated position. Space Flight Medicine literature review identified that cognitive deficits could occur within three and a half minutes for a deconditioned crew, affecting their ability to take action if required. They also concluded that uprighting should be complete within seven minutes to prevent a decrease in blood pressure and loss of consciousness to the crew. This could be met through a variety of mechanisms in addition to uprighting, such as allowing crewmember seat egress. See Barr, Y & Fogarty, J (2010). Assessment of Prone Positioning of Restrained, Seated Crewmembers in a Post Landing Stable 2 Orion Configuration, JSC-CN-19414.]

6.5.7 Crew Limits in Launch Orientation

[V2 6113] The time in which crewmembers are on back with feet elevated in a launch configuration **shall not** exceed 3 hours and 15 minutes, excluding subsequent safing and egress time.

[Rationale: This position can be extremely fatiguing, painful, and cause musculoskeletal discomfort and difficulty urinating. These effects have the potential to impair a crewmember's ability to perform launch duties, emergency egress procedures, and post launch tasks, and, coupled with the length of the crew day, can also affect cognitive performance. The time interval ends with lift-off. The "crew time on back" is the period from the first crewmember's adoption of an on-back posture until launch or, in the event of a scrub, until vehicle safing begins. This time accounts for crew ingress and hold time leading to the planned launch time. It does not include vehicle safing or egress time.]

6.6 Acoustics

This section establishes requirements to ensure an acceptable acoustic environment to preclude noise-related hearing loss and interference with communications and to support human performance. For specifications on using sound to relay information, see section 10.3.4, Audio Displays, in this NASA Technical Standard. Table 6, Acoustic Limits for Launch, Entry, and Abort Phases, and Table 7, Acoustic Limits for On-Orbit, Lunar, and Planetary Operations Phase are summaries of the acoustic requirements listed in the following sections, referenced by requirement number.

To ensure that an integrated vehicle (including suit systems) meets the acoustic limits, it is necessary to develop an Acoustic Noise Control Plan that establishes the overall noise control *strategy, acoustic limit allocations, acoustic testing, analyses, remedial action steps, schedule, and follow-up activities. This plan needs to be initially released early in the design cycle and then updated as new data and design information become available. The included acoustic limit allocations would define a set of allocated and sub-allocated acoustic limits for systems, sub-systems, and hardware components so that the total contributions of all hardware will result in compliance with this NASA Technical Standard. As part of the Acoustic Noise Control Plan, it is best practice to verify acoustic requirements with test of the actual flight hardware. Modeling the acoustic environment of the vehicle with measured noise sources and propagation paths is best practice. Small design changes or even different part numbers of the same design such as with fans can change the acoustic level. Previous space flight experience has shown that without such a plan, it is difficult to develop an integrated system that can meet acoustic limits.*

Table 6—Acoustic Limits for Launch, Entry, and Abort Phases

Mission Phase	24-Hour Hazardous Noise Exposure Limits	Ceiling	Impulse Noise	Infrasonic Noise 1-20 Hz	Referenced Requirements
Launch	Noise dose ≤100, equivalent to 8-hour 85 dBA TWA	≤105 dBA allows 10 dBA headroom for Personal Comm	≤140 dB peak SPL†	<150 dB*	V2 6073 V2 6074 V2 6076 V2 6085
Entry	Noise dose ≤100, equivalent to 8-hour 85 dBA TWA	≤105 dBA allows 10 dBA headroom for Personal Comm	≤140 dB peak SPL	<150 dB*	V2 6073 V2 6074 V2 6076 V2 6085
Launch Abort	Noise dose ≤100, equivalent to 8-hour 85 dBA TWA	≤115 dBA	≤140 dB peak SPL	< 150 dB*	V2 6073 V2 6075 V2 6076 V2 6085
Personal Communication	Noise dose ≤100, equivalent to 8-hour 85 dBA TWA	≤115 dBA	≤140 dB peak SPL	Not Applicable	V2 6073 V2 6076 V2 6106

**Hearing protection CANNOT be used to satisfy this limit.*
† Sound Pressure Level

Table 7—Acoustic Limits for On-Orbit, Lunar, and Planetary Operations Phase*

Mission Phase	24-Hour Hazardous Noise Exposure Limits	Continuous Noise	Hazardous Noise	Intermittent Noise	Impulse Noise	Referenced Requirements
On-Orbit	Noise dose ≤100, equivalent to 8-hour 75 dBA TWA	NC-50 Octave Band SPL limits. See Figure 9 and Table 8	<85 dBA	Specified Sound Level (dBA) depending on duration, see Table 6	≤140 dB peak SPL	V2 6077 V2 6078 V2 6080 V2 6083
a. For Sleep on Missions >30 days	Noise dose ≤100, equivalent to 8-hour 75 dBA TWA	NC-40 Octave Band SPL limits. See Figure 9 and Table 8	<85 dBA	+10 dBA or less above background	+10 dB peak or less above background	V2 6077 V2 6079 V2 6082
b. For Sleep on Missions ≤30 days	Noise dose ≤100, equivalent to 8-hour 75 dBA TWA	NC-50 Octave Band SPL limits. See Figure 9 and Table 8	<85 dBA	+10 dBA or less above background	+10 dB peak or less above background	V2 6077 V2 6078 V2 6079 V2 6082

**Hearing protection CANNOT be used to satisfy these limits.*

6.6.1 Acoustic Limits

6.6.1.1 Launch, Entry, and Abort Noise Exposure Limits

[V2 6073] During launch, entry, and abort operations, the noise exposure level (not including impulse noise) at the crewmember's ear, calculated over any 24-hour period, **shall** be limited such that the noise dose (D) is ≤100:

$$D = 100\sum_{n=1}^{N}\frac{C_n}{T_n}, \quad \text{(Eq.1)}$$

where:
N = the number of noise exposure events during the 24-hour period
C_n = the actual duration of the exposure event in minutes
T_n = the maximum noise exposure duration allowed, based on the specific sound level (L_n) of an exposure event in dBA, calculated using the following equation:

$$T_n = \frac{480}{2^{(L_n - 85)/3}} \quad \text{(Eq. 2)}$$

[Rationale: A noise dose of D = 100 is equivalent to an 8-hour, 85 dBA time-weighted average (TWA) using a 3 dB exchange rate. Equivalent noise exposure levels above 85 dBA for more than 8 hours have been shown to increase the risk of noise-induced hearing loss. The above formulae can be used to calculate the 24-hour noise exposure levels based on the 8-hour, 85 dBA criterion recommended by National Institute for Occupational Safety and Health (NIOSH),

using the 3 dB trading rule. The noise attenuation effectiveness of hearing protection or communications headsets may be used to satisfy this requirement. Any planned use of hearing protection to satisfy this requirement is to be well documented and approved. Requirements established to meet this requirement are to be included in the Acoustic Noise Control Plan. The Acoustic Noise Control Plan allocates noise levels to individual components and is maintained to ensure that the total system meets the levels defined in this NASA Technical Standard.]

6.6.1.2 Ceiling Limit for Launch and Entry

[V2 6074] During launch and entry operations, the system **shall** limit the combined A-weighted sound levels (not including impulse noise) at the crewmembers' ears to a maximum of 105 dBA.

[Rationale: Noise levels above 115 dBA have been shown to produce noise-induced hearing loss. In cases where audio communications are required, e.g., launch, entry, a 105 dBA limit is recommended to allow 10 dB of headroom for alarms and voice communications. The noise attenuation effectiveness of hearing protection or communications headsets may be used to satisfy this requirement; however, any planned use of hearing protection is to be well documented and approved. Requirements established to meet this requirement are to be included in the Acoustic Noise Control Plan.]

6.6.1.3 Ceiling Limit for Launch Abort

[V2 6075] During launch abort operations, the system **shall** limit the combined A-weighted sound levels (not including impulse noise) at the crewmembers' ears to a maximum of 115 dBA.

[Rationale: Noise levels above 115 dBA have been shown to produce noise-induced hearing loss. In cases where no audio communications are required, e.g., during abort operations, there is no need to allow 10 dB of headroom for alarms and voice communications. The noise attenuation effectiveness of hearing protection or communications headsets may be used to satisfy this requirement; however, any planned use of hearing protection is to be well documented and approved.]

6.6.1.4 Launch, Entry, and Abort Impulse Noise Limits

[V2 6076] During launch, entry, and abort operations, impulse noise measured at the crewmember's ear location **shall** be limited to less than 140 dB peak SPL.

[Rationale: A limit of 140 dB peak SPL for impulse noise prevents trauma to the hearing organs caused by impulse noise (MIL-STD-1474, current version, Department of Defense Design Criteria Standard, Noise Limits). The noise attenuation effectiveness of hearing protection or communications headsets may be used to satisfy this requiremen; however, any planned use of hearing protection to satisfy this requirement is to be well documented and approved. Requirements established to meet this requirement are to be included in the Acoustic Noise Control Plan.]

6.6.1.5 Hazardous Noise Limits for All Phases Except Launch, Entry, and Abort

[V2 6077] For off-nominal operations, broadcast communications, depressurization valves, and maintenance activities, the A-weighted sound level (excluding impulse noise and alarm signals) **shall** be less than 85 dBA, regardless of time duration; except in the case of depressurization valves, the noise attenuation effectiveness of hearing protection or communications headsets may not be used to satisfy this requirement.

[Rationale: The 85 dBA overall SPL defines the hazardous noise limit during all phases except launch, entry, and abort, at which action to reduce the noise level is to be taken so that interference with voice communications and alarms, as well as increased risk for hearing loss, does not occur. This is to help ensure that the habitable volume is safe. This is not intended for nominal hardware emissions but to limit the sound level of sources such as communications systems, depressurization valves, and levels that occur during planned off-nominal operations and maintenance activities. Nominal on-orbit acoustic levels are limited by requirements [V2 6078] Continuous Noise Limits and [V2 6080] Intermittent Noise Limits of this NASA Technical Standard.]

6.6.1.6 24-Hour Noise Exposure Limits

[V2 6115] The noise exposure level (not including impulse noise) at the crewmember's ear, calculated over any 24-hour period, except during launch, entry, and abort operations, **shall** be limited such that the noise dose (D) is ≤100:

(Eq. 3)

$$D = 100\sum_{n=1}^{N}\frac{C_n}{T_n},$$

where:

N = the number of noise exposure events during the 24-hour period
C_n = the actual duration of the exposure event in minutes
T_n = the maximum noise exposure duration allowed, based on the specific sound level

(L_n) of an exposure event in dBA, calculated using the following equation:

(Eq. 4)

$$\boldsymbol{T_n = \frac{480}{2^{(L_n-75)/3}}}$$

[Rationale: A noise dose of D = 100 is equivalent to an 8-hour, 75 dBA time-weighted average (TWA) using a 3 dB exchange rate. Equivalent noise exposure levels above 75 dBA for more than 8 hours have been shown to increase the risk of noise-induced hearing loss. The above formulae can be used to calculate the 24-hour noise exposure levels based on the 8-hour, 75 dBA criterion recommended by the World Health Organization (WHO), using the 3 dB trading rule, which corresponds to a 24-hour noise exposure level of 70 dBA. The noise attenuation

effectiveness of hearing protection or communications headsets may not be used to satisfy this requirement. Requirements established to meet this are to be included in the Acoustic Noise Control Plan. The Acoustic Noise Control Plan allocates noise levels to individual components and is maintained to ensure that the total system meets the levels defined in this NASA Technical Standard.]

6.6.1.7 Continuous Noise Limits

[V2 6078] In spacecraft work areas, where good voice communications and habitability are required, SPLs of continuous noise (not including impulse noise) **shall** be limited to the values given by the Noise Criterion (NC)-50 curve in Figure 11, NC Curves, and Table 8, Octave Band SPL Limits for Continuous Noise, dB re 20 µPa (micropascals); hearing protection cannot be used to satisfy this requirement.

[Rationale: NC-50 limits noise levels within the habitable volume to allow adequate voice communications and habitability during mission operations. The noise limit at 16 kHz does not appear in Figure 11 but is given in Table 8. SPLs for continuous noise do not apply to alarms, communications, or noise experienced during maintenance activities. The corresponding spacesuit requirement is defined in requirement [V2 11009] Continuous Noise in Spacesuits, in this NASA Technical Standard.]

6.6.1.8 Crew Sleep Continuous Noise Limits

[V2 6079] For missions greater than 30 days, SPLs of continuous noise **shall** be limited to the values given by the NC-40 curve (see Figure 11, NC Curves, and Table 8, Octave Band SPL Limits for Continuous Noise, dB re 20 µPa) in crew quarters and sleep areas. Hearing protection cannot be used to satisfy this requirement.

[Rationale: For a crewmember to relax the auditory system, a quiet environment is to be provided during crew sleep; the NC-40 limit provides adequate auditory rest. The noise limit at 16 kHz does not appear in Figure 9 but is given in Table 8. For missions 30 days or less in duration (short-duration missions), acoustic levels during sleep are limited by the requirement [V2 6078] Continuous Noise Limits (NC-50). Intermittent and impulse noise during sleep are controlled by the requirement [V2 6082] Annoyance Noise Limits for Crew Sleep.]

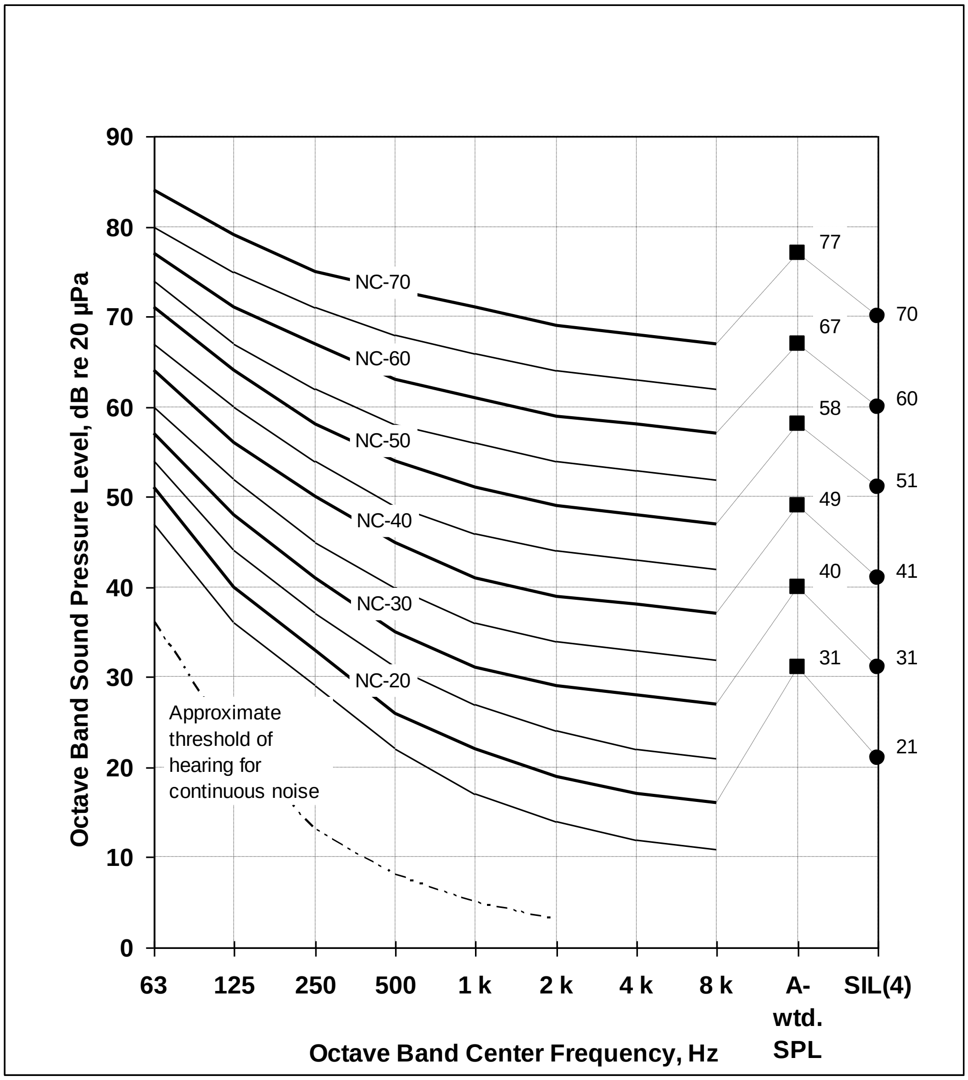


Figure 11—NC Curves

Note: Corresponding A-weighted SPLs and speech interference levels (SILs) are given for reference only (Beranek and Vér, 1992). SIL (4) is Speech Interference Level, 4-band method.

Table 8—Octave Band SPL Limits for Continuous Noise, dB re 20 µPa

Octave Band Center Frequency (Hz)										
	63	125	250	500	1 k	2 k	4 k	8 k	16 k	NC
Work Areas Maximum (NC-50)	71	64	58	54	51	49	48	47	46	50
Sleep Areas Maximum (NC-40)	64	56	50	45	41	39	38	37	36	40

6.6.1.9 Intermittent Noise Limits

[V2 6080] For hardware items that operate for eight hours or less (generating intermittent noise), the maximum noise emissions (not including impulse noise), measured 0.6 m from the loudest hardware surface, **shall** be determined according to Table 9, Intermittent Noise A-Weighted SPL and Corresponding Operational Duration Limits for any 24-hour period (measured at 0.6 m distance from the source). Hearing protection cannot be used to satisfy this requirement.

[Rationale: Table 9 limits crew exposure to intermittent noise levels of hardware items that are inherently noisy but that operate for short time periods. Intermittent sources can result in unacceptable noise levels, add to the overall crew noise exposure, impede communications, and cause disruption in crew rest/sleep.]

Table 9—Intermittent Noise A-Weighted SPL and Corresponding Operational Duration Limits for any 24-Hour Period (measured at 0.6 m distance from the source)

Maximum Noise Duration per 24-hr Period	Sound Pressure Level (dBA re 20 µPa)
8 hr	≤49
7 hr	≤50
6 hr	≤51
5 hr	≤52
4.5 hr	≤53
4 hr	≤54
3.5 hr	≤55
3 hr	≤57
2.5 hr	≤58
2 hr	≤60
1.5 hr	≤62
1 hr	≤65
30 min	≤69
15 min	≤72
5 min	≤76
2 min	≤78
1 min	≤79
Not allowed *	≥80

** To leave a margin from the 85-dBA nominal hazardous noise limit*

6.6.1.10 Alarm Maximum Sound Level Limit

[V2 6081] The maximum alarm signal A-weighted sound level **shall** be less than 95 dBA at the operating position of the intended receiver.

[Rationale: This allows alarm sound levels to exceed the 85 dBA hazard limit because of the need for alarm audibility. Also, alarms can be silenced at the crew's discretion.]

6.6.1.11 Annoyance Noise Limits for Crew Sleep

[V2 6082] With the exception of communications and alarms, the system **shall** limit impulse and intermittent noise levels at the crewmember's head location to 10 dB above background noise levels during crew sleep periods. Hearing protection cannot be used to satisfy this requirement.

[Rationale: Impulse and intermittent noise is to be limited to 10 dB or less above the background noise to avoid waking crewmembers who are sleeping. Communications and alarms are not subject to this requirement.]

6.6.1.12 Impulse Noise Limit

[V2 6083] The system **shall** limit impulse noise measured at the crewmember's head location to less than 140 dB peak SPL during all mission phases except launch and entry. Hearing protection cannot be used to satisfy this requirement.

[Rationale: A limit of 140-dB peak SPL for impulse noise prevents acoustic trauma (MIL-STD-1474, current version).]

6.6.1.13 Narrow-Band Noise Limits

[V2 6084] The maximum SPL of narrow-band noise components and tones **shall** be limited to at least 10 dB less than the broadband SPL of the octave band that contains the component or tone.

[Rationale: Narrow-band noise component and tone levels should be limited to 10 dB below the broadband level to prevent irritating and distracting noise conditions which could affect crew performance.]

6.6.1.14 Infrasonic Sound Pressure Limits

[V2 6085] Infrasonic SPLs, including frequencies from 1 to 20 Hz but not including impulse noise, **shall** be limited to less than 150 dB at the crewmember's head location. Hearing protection cannot be used to satisfy this requirement.

[Rationale: The 150 dB limit for infrasonic noise levels in the frequency range from 1 to 20 Hz provides for health and well-being effects. (Refer to ACGIH, Threshold Limit Values (TLVs®), Infrasound and Low-Frequency Sound, 2001.)]

6.6.1.15 Noise Limit for Personal Audio Devices

[V2 6106] The system **shall** limit the maximum A-weighted sound level at the crewmember's ear created by a personal audio device to 115 dBA or less.

[Rationale: Noise levels above 115 dBA have been shown to produce noise-induced hearing loss. Sound levels produced by personal audio devices are allowed to be at high levels to

overcome the noise generated during launch and descent. A personal audio device may be an integrated part of the EVA helmet or an independent communication or listening headset but does not include cabin or broadcast speakers. OSHA identifies 115 dBA as the allowable ceiling for noise exposure limits. This ceiling limit is allowed as long as it does not result in the overall daily TWA exposure exceeding the limit of 85 dBA per requirement [V2 6073] Launch, Entry, and Abort Noise Exposure Limits.]

6.6.2 Acoustic and Noise Monitoring

6.6.2.1 Acoustic Monitoring

[V2 6087] Broadband and frequency-dependent SPLs **shall** be monitored and quantified as needed for crew health and safety.

[Rationale: Acoustic monitoring is needed to ensure that sound levels during the mission are below established limits for crew health and performance. Periodically on ISS, the crew uses acoustic monitors to monitor their environment.]

6.6.2.2 Individual Noise Exposure Monitoring

[V2 6088] Noise exposure levels **shall** be monitored and quantified for each crewmember as needed for crew health and safety.

[Rationale: To protect the crew from excessive noise exposure, the noise exposure experienced by the crew is to be understood. Understanding of noise exposure is critical to the protection of crew hearing and helps determine the degree of remedial actions, including moving to a different environment, hardware shutdown, or proper implementation of countermeasures. Periodically on ISS, the crew uses acoustic monitors to monitor their environment.]

6.7 Vibration

Limiting crew exposure to vibration is important for mission success. Excessive whole-body vibration can cause injury, fatigue, discomfort, and vision degradation, whereas the primary risk resulting from hand vibration is reduced fine motor control.

6.7.1 Whole Body Vibration

6.7.1.1 Vibration during Preflight

[V2 6089] The system **shall** limit vibration to the crew such that the frequency-weighted acceleration between 0.1 to 0.5 Hz in each of the X, Y, and Z axes is less than 0.05 g (0.5 m/s^2) root mean square (RMS) for each 10-minute interval during prelaunch (when calculated in accordance with ISO 2631-1:1997(E), Mechanical Vibration and Shock -

Evaluation of Human Exposure to Whole-Body Vibration - Part 1: General Requirements, Annex D, Equation D-1).

[Rationale: Low-frequency vibration, especially in the range between 0.1 and 0.5 Hz, has the potential to cause motion sickness over relatively short exposure periods. This may be encountered while the crew is in the vehicle during the prelaunch period, given that a tall vehicle stack may be susceptible to back-and-forth sway. Reducing the amount of sway will prevent the onset of motion sickness during the prelaunch phase. According to ISO 2631-1: 1997(E), Annex D, the percentage of unadapted adults who may vomit is equal to 1/3 motion sickness dose value. The value 0.05 g weighted RMS acceleration indicates that approximately 14% or one out of seven crewmembers may vomit. Although ISO 2631-1:1997(E) limits the acceleration measurement for assessing motion sickness to the vertical direction, this is based on the assumption that the human is in the seated upright posture. Since occupants of a vehicle are likely to be in the semi-supine posture, the requirement is applied to all three orthogonal axes (X, Y, and Z). The purpose of the 10-minute integration time is to constrain the deviations around the permitted average sway during a 2-hour prelaunch period.]

6.7.1.2 Vibration Exposures during Dynamic Phases of Flight

[V2 6090] The system **shall** limit vibration during dynamic phases of flight to the crew such that the vectorial sum of the X, Y, and Z accelerations between 0.5 and 80 Hz, calculated in 1-s intervals and weighted in accordance with ISO 2631-1:1997(E), is less than or equal to the levels plotted for the accumulated durations in Table 10, Frequency-Weighted Vibration Limits by Exposure Time during Dynamic Phases of Flight, and Figure 12, Frequency-Weighted Vibration Limits by Exposure Time during Dynamic Phases of Flight.

[Rationale: Although there are limited data on the effects of high levels of vibration on health, especially during concurrent hypergravity acceleration, i.e., >1-g bias, internal organs and tissue structures may be damaged if the vibration amplitude goes over these time durations. This duration (under 10 minutes) is expected to bracket the vibration period during ascent and return. If the dynamic event exceeds this 10-minute duration, requirement [V2 6091] Long-Duration Vibration Exposure Limits for Health during Non-Sleep Phases of Mission has to be used from the 10-minute point onward. In accordance with ISO 2631-1, Section 6.3.1, vibration calculations are based on a running 1-second time window.]

Table 10—Frequency-Weighted Vibration Limits by Exposure Time during Dynamic Phases of Flight

Maximum Vibration Exposure Duration per 24-hr Period	Maximum Frequency-Weighted Acceleration
10 min	3.9 m/s^2 RMS (0.4 g RMS)
1 min	5.9 m/s^2 RMS (0.6 g RMS)

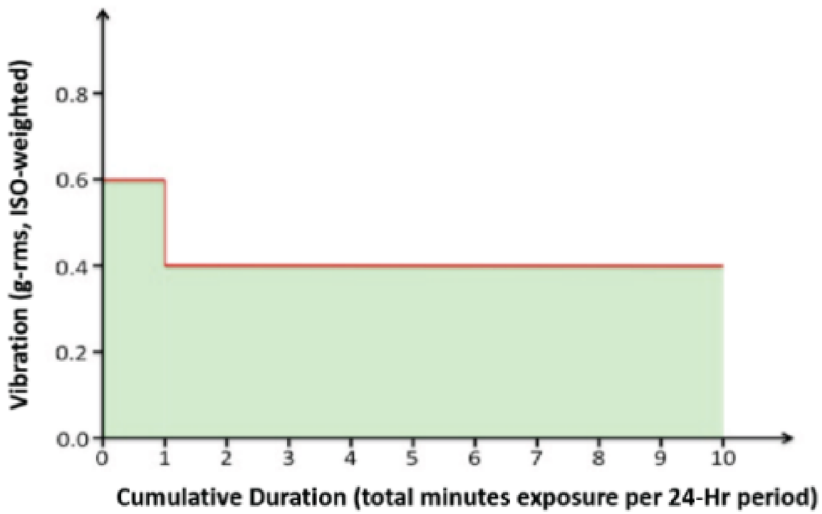


Figure 12—Frequency-Weighted Vibration Limits by Exposure Time during Dynamic Phases of Flight

6.7.1.3 Long-Duration Vibration Exposure Limits for Health during Non-Sleep Phases of Mission

[V2 6091] The system **shall** limit vibration to the crew such that the vectorial sum of the X, Y, and Z frequency-weighted accelerations, as computed according to ISO 2631-1:1997(E), do not exceed the minimum health guidance caution zone level defined by Figure B.1 in ISO 2631-1:1997(E), Annex B.

[Rationale: Biodynamic and epidemiological research provides evidence of elevated health risk related to long-term exposure to high-intensity whole-body vibration. According to ISO 2631-1:1997(E) Annex B.3.1, "[f]or exposures below the [health guidance caution] zone, health effects have not been clearly documented and/or objectively observed."]

6.7.1.4 Vibration Exposure Limits during Sleep

[V2 6092] The system **shall** limit vibration to the crew such that the acceleration between 1.0 and 80 Hz in each of the X, Y, and Z axes, weighted in accordance with ISO 20283-5, Mechanical Vibration—Measurement of Vibration on Ships; Part 5 - Guidelines for the Measurement, Evaluation and Reporting of Vibration with Regard to Habitability on Passenger and Merchant Ships, Annex A, is less than 0.01 g (0.1 m/s^2) RMS for each two-minute interval during the crew sleep period.

[Rationale: For long-duration (approximately eight hours), smaller vibration exposure can adversely affect crew sleep.]

6.7.1.5 Vibration Limits for Performance

[V2 6093] Crew tasks **shall** be evaluated for performance (e.g., motor control accuracy and precision, vision/readability, speech clarity, attentional focus) for all expected (nominal and off-nominal) vibration levels.

[Rationale: It is critical to ensure that the crew can perform mission tasks in the environment to which they will be exposed. For example, ascent and landing are typically accompanied by periods of significant vibration that can affect the crewmembers' motor control and visual performance. Off-nominal conditions such as an aborted launch will expose crewmembers to challenging vibration levels that will limit their ability to perform functions such as reading display panels, turning knobs, activating switches, using touch screens and/or utilizing joystick controllers.]

6.7.2 Hand Vibration

[V2 6094] The system, including tools, equipment, and processes, **shall** limit vibration to the crewmembers' hands such that the accelerations, as computed according to ANSI/ASA S2.70-2006, Guide for the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hand, do not exceed the Daily Exposure Action Value defined by ANSI/ASA S2.70-2006, Annex A, Figure A.1.

[Rationale: In accordance with ANSI/ASA S2.70-2006, Annex A.1.1, the Daily Exposure Action Value delineates the health risk threshold defined as "the dose of hand-transmitted vibration exposure sufficient to produce abnormal signs, symptoms, and laboratory findings in the vascular, bone or joint, neurological, or muscular systems of the hands and arms in some exposed individuals."]

6.8 Radiation

6.8.1 Ionizing Radiation

Crew occupational exposure to ionizing radiation (radiation consisting of particles, X-rays, or gamma rays with sufficient energy to cause ionization in the medium through which it passes) is managed through system design, in-flight monitoring and procedures, mission architecture and planning, and the application of appropriate countermeasures. Space Permissible Exposure Limits (PELs) are specified in NASA-STD-3001, Volume 1, and include career cancer risk limits and dose limits for short–term and career non-cancer effects. As defined in NASA-STD-3001, Volume 1, exposures are maintained as low as reasonably achievable (ALARA) to ensure *astronauts do not approach radiation limits and that such limits are not considered as tolerance values. In practice, the application of the ALARA principle dictates that actions be taken during design and operational phases to manage and limit exposures to ionizing radiation.*

6.8.1.1 Ionizing Radiation Protection Limit

[V2 6095] The program **shall** set system design requirements to prevent potential crewmembers from exceeding PELs as set forth in NASA-STD-3001, Volume 1.

[Rationale: The radiation design requirement is imposed to limit the risk of exposure-induced death (REID) and to prevent clinically significant health effects, including performance degradation or sickness in-flight as discussed in NASA-STD-3001, Volume 1. The mission scenario and prior crewmember exposure are to be considered for mission planning and allocation of system design limits across architectural elements, including EVA. The program is to consider the cumulative REID over several missions for individual astronauts in setting the design requirements. This allows experienced crewmembers to potentially support multiple missions; however, the minimum functionality of protection to the most restrictive career limit does not allow unrestricted crew selection related to a crewmember having prior radiation exposures. That is, previous exposures are to be taken into account during crew selection to ensure that career PELs are not violated. Examples of the various mission and crew selection scenarios are discussed in the HIDH.]

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[V2 6096] Requirement deleted.

6.8.1.2 Crew Radiation Exposure Limits

[V2 6097] The program/project **shall** design systems using the ALARA principle to limit crew radiation exposure.

[Rationale: 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 tolerance values. ALARA is an iterative process of integrating radiation protection into the design process, ensuring optimization of the design to afford the most protection possible, within other constraints of the vehicle systems. The protection from radiation exposure is ALARA when the expenditure of further resources would be unwarranted by the reduction in exposure that would be achieved.]

6.8.1.3 Radiation Environments

[V2 6098] The program **shall** specify the radiation environments to be used in verifying the radiation design requirements.

[Rationale: The relevant space radiation environment is to be used in establishing system design requirements, vehicle design and development of all program architectural elements, and verification of requirements. System design requirements derived from the uncertainty in the calculation of cancer career risk limits are to specify the relevant radiation environment used in determining the requirement. Relevant space radiation parameters include solar maximum and minimum conditions, energy spectra, or precise model inputs, assumptions, and model options.]

6.8.1.4 Space Weather Monitoring

[V2 6099] The program **shall** set requirements specifying appropriate capabilities to be provided for real-time monitoring of space weather (solar particle events (SPE), galactic cosmic rays (GCR), etc.) for characterization of the radiation environment and operational response by ground personnel and the crew.

[Rationale: Radiation protection for humans in space differs from that on Earth because of the distinct types of radiation, the small population of workers, and the remote location of astronauts during space flight. Radiation sources in space have distinct physical and biological damage properties compared to terrestrial radiation, and the spectrum and energy of concern for humans differ from that for electronics. Space weather can directly impact a broad portion of the space radiation environment on short- and long-time scales. Space weather conditions are to be known at all times during missions to allow for appropriate radiation protection planning.]

6.8.1.5 Ionizing Radiation Alerting

[V2 6100] The system **shall** include a method to alert the crew locally and remotely when radiation levels are expected to exceed acceptable levels.

[Rationale: The data from charged particle monitoring are the fundamental environmental information required for radiation transport calculations and crew exposure evaluation. Given an accurately measured energy spectra incident on the vehicle during an SPE, detailed crew exposure can be evaluated. This limits the uncertainty of a single absorbed dose measurement in determining crew exposure from an SPE. The crew, at all times, is to be alerted to excessive fluence of particles. Should communications from the ground be interrupted or lost, the crew requires onboard warnings when the radiation environment crosses dangerous thresholds so that appropriate countermeasure actions can be taken. Varying user-defined thresholds may be set according to the radiation environmental conditions that may be encountered, depending on mission phase. The intent is for the vehicle data management system to provide the alerting functionality. Crew need to be given sufficient time to prepare for a high radiation event.]

6.8.1.6 Ionizing Radiation Dose Monitoring

[V2 6101] To characterize and manage radiation exposures, the program **shall** provide methods for monitoring personal dose and dose equivalent exposure, ambient monitoring of particle fluence as a function of direction, energy, and elemental charge and monitoring of ambient dose and ambient dose equivalent.

[Rationale: These measurements are the primary means for controlling crew exposure during missions to ensure that short-term and career space PELs, as specified in NASA-STD-3001, Volume 1, are not exceeded. Tissue-equivalent micro-dosimeters have been used extensively for crew exposure monitoring in space for this purpose. There is a large set of data and calculations in the published literature that can be directly applied to crew exposure and risk determination, using tissue-equivalent micro-dosimeters. Passive area monitors provide a time-integrated measure of the spatial distribution of exposure rates. The exposure rates change with stowage reconfigurations. Knowledge of the spatial distribution of exposure rate is necessary to identify areas that have a relatively high exposure rate, i.e., avoidance areas, and to reconstruct a crewmember's exposure in the event of lost or unusable personal dosimeter data. The data are used to track the crew exposure throughout the mission, as well as to provide positive indication of proper health and status of the absorbed dose instrument. Passive dosimeters collect data even during situations when power is lost to other instruments. Radiation data are vital for quantifying in-flight risks to the crew and for allowing mission operations to advise the crew on appropriate action in response to an SPE. For periods of time when the crew is not in communication with mission operations, the crew is to be able to ascertain the radiation conditions within the vehicle and take appropriate actions as required. The changes in the radiation environment that could cause additional crew exposure can occur in time periods as small as 1 to 5 minutes. The corresponding EVA spacesuit requirement for radiation dose monitoring is defined in requirement [V2 11010] EVA Suit Radiation Monitoring in this NASA Technical Standard.]

6.8.2 Non-Ionizing Radiation

Sources of non-ionizing radiation are present in space flight applications, and exposure is potentially hazardous. Astronaut occupational exposure to non-ionizing radiation is managed through mission architecture, system design, procedures and planning, and application of appropriate countermeasures. This NASA Technical Standard classifies non-ionizing radiation into four categories: radio frequency (RF) electromagnetic radiation, lasers, natural incoherent light, and artificial incoherent light.

6.8.2.1 RF Non-Ionizing Radiation Exposure Limits

[V2 6102] The system **shall** maintain the crew exposure to RF electromagnetic fields to or below the limits stated in Table 11, Maximum Permissible Exposure (MPE) to RF Electromagnetic Fields, and shown graphically in Figure 13, RF Electromagnetic Field Exposure Limits.

[Rationale: Examples of devices that generate radio frequency radiation include, but are not limited to, antennas and wireless systems. These limits are modified from the C95.1-2005, Institute of Electrical and Electronic Engineers (IEEE). They are intended to establish exposure conditions for radio-frequency and microwave radiation to which it is believed that nearly all workers can be repeatedly exposed without injury. Modifications were made to the C95.1-2005 power density values to remove a safety margin that was added in the C95.1 standard to include the children population. This is not applicable to astronaut corp and resulted in the relaxation of

the C95.1-2005 limits as per Figure 5.7.3.2.1-1, Occupational Exposure Limits for Radio-Frequency Electromagnetic Fields.]

Table 11—Maximum Permissible Exposure (MPE) to RF Electromagnetic Fields (modified from IEEE C95.1-2005, lower tier)

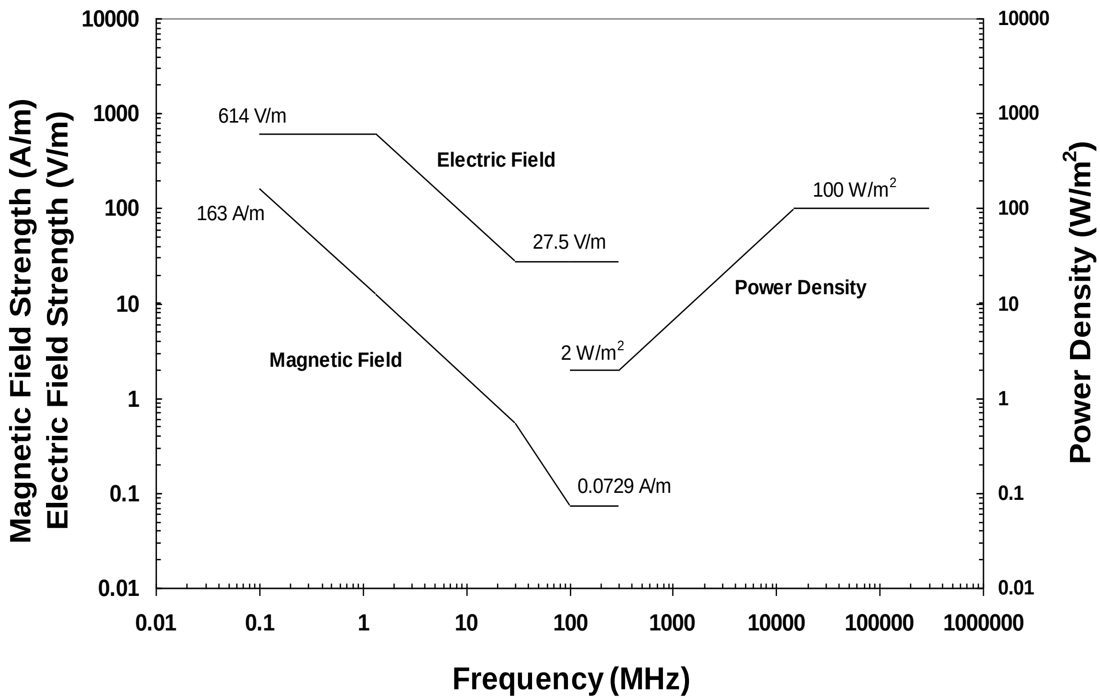
Frequency Range (MHz)	RMS Electric Field Strength (E)[a] (V/m)	RMS Magnetic Field Strength (H)[a] (A/m)	RMS Power Density (S) E–Field, H–Field (W/m^2)	Averaging Time[b] $\|E\|^2$, $\|H\|^2$, or S (min)	
0.1 – 1.34	614	$16.3/f_M$	$(1{,}000,\ 100{,}000/f_M^2)$ [c]	6	6
1.34 – 3	$823.8/f_M$	$16.3/f_M$	$(1{,}800/f_M^2,\ 100{,}000/f_M^2)$	$f_M^2/0.3$	6
3 – 30	$823.8/f_M$	$16.3/f_M$	$(1{,}800/f_M^2,\ 100{,}000/f_M^2)$	30	6
30 – 100	27.5	$158.3/f_M^{1.668}$	$(2,\ 9{,}400{,}000/f_M^{3.336})$	30	$0.0636 f_M^{1.337}$
100 – 300	27.5	0.0729	2	30	30
300 - 5000	–	–	$f/150$	30	
5000 - 15000	–	–	$f/150$	$150/f_G$	
15000 – 30,000	–	–	100	$150/f_G$	
30,000 – 100,000	–	–	100	$25.24/f_G^{0.476}$	
100,000 – 300,000	–	–	100	$5048/[(9f_G-700)f_G^{0.476}]$	

Note: f_M is the frequency in MHz; f_G is the frequency in GHz.

(a) For exposures that are uniform over the dimensions of the body such as certain far-field plane-wave exposures, the exposure field strengths and power densities are compared with the MPEs in the table. For non-uniform exposures, the mean values of the exposure fields, as obtained by spatially averaging the squares of the field strengths or averaging the power densities over an area equivalent to the vertical cross section of the human body (projected area) or a smaller area, depending on the frequency, are compared with the MPEs in the table. For further details, see IEEE C95.1-2005, notes to Table 8 and Table 9.

(b) The left column is the averaging time for $|E|^2$; the right column is the averaging time for $|H|^2$. For frequencies greater than 400 MHz, the averaging time is for power density (S).

(c) These plane-wave equivalent power density values are commonly used as a convenient comparison with MPEs at higher frequencies and are displayed on some instruments in use.



(Illustrated to show whole-body resonance effects around 100 MHz) (modified from IEEE C95.1-2005, lower tier)

Figure 13—RF Electromagnetic Field Exposure Limits

6.8.2.2 Laser Exposure Limits

[V2 6103] The system **shall** maintain the crew ocular and dermal exposure to laser systems and the ocular exposure of the uncontrolled ground population to space lasers to or below the limits specified in ANSI Z136.1, 2014, American National Standard for Safe Use of Lasers, Table 5 (ocular) and Table 7 (dermal) without Personal Protective Equipment.

[Rationale: This requirement limits crew ocular and dermal exposure to both continuous and repetitively pulsed lasers to protect against eye injury. The limits are adopted from the Laser Institute of America's (LIA) publication ANSI Z136.1, 2014. The term laser system includes the laser, its housing, and controls. This requirement applies to laser systems utilized both internal and external to the vehicle. The safety analysis of all lasers will be carried out by ANSI Z136.1 methodology as specified in the verification requirement. In addition, this requirement limits uncontrolled ground population ocular exposure to space lasers. The limits are adopted from ANSI Z136.1, 2014. ANSI Z136.6, 2015 may be used for guidance on laser hazard analysis methodology.]

6.8.2.3 Natural Sunlight Exposure Limits

[V2 6104] The system **shall** maintain the crew exposure to natural sunlight for spectral radiance or irradiance (as applicable) within wavelengths between 180 nm and 3000 nm, as noted in Table 12, Natural Sunlight Exposure Limits for Different Damage Mechanisms.

[Rationale: This requirement is intended to prevent ocular and dermal injury from sunlight exposure with wavelengths between 180 and 3000 nm. Any exposure should consider the entire window configuration of the incident radiation prior to its interaction with a crewmember's body, including any concentration, diffusion, or filtering. The transmittance required for windows, visors, and other optical devices can be reconciled with protection from natural sunlight through the use of protective personal equipment, temporary filters, proper material selection, apertures, or other appropriate means. The sun subtends an angle of approximately 9 milliradians when observed from the Earth and is, therefore, considered a small source. The limits are based on the methodology given in the 2014 American Conference of Governmental Industrial Hygienists (ACGIH) standard, Threshold Limit Values® (TLVs) and Biological Exposure Indices® (BEIs), sections Light and Near-Infrared Radiation and Ultraviolet Radiation (2014 or newer). This requirement is applicable to both hatch and module windows.]

Table 12—Natural Sunlight Exposure Limits for Different Damage Mechanisms

Requirement	ACGIH 2014 – TLVs Equations in the Optical Radiation Section	Units	Pass Criteria	Damage Mechanism
Visible and Near-Infrared Radiation 380-3000 nm (relaxed 2x)	Equations 4a, 4b (Section 1)*	Seconds (Eq. 4a) Factors over allowable irradiance (Eq. 4b)	$T_{max} \geq 0.25$s (Eq. 4a) Weighted irradiance divided by TLV ratio ≤ 1 (Eq. 4b)	Retinal Thermal
Visible Radiation 305-700 nm (relaxed 5x)	Equation 8b (Small Source) (Section 2)*	Seconds (Eq. 8b)	$T_{max} \geq 0.25$ sec (Eq. 8b)	Retinal Photochemical
Ultraviolet Exposure 180-400 nm (not relaxed)	Equations 3, 4 (Ultraviolet Radiation)*	Minutes (Eq. 3, Eq. 4)	$T_{max} \geq 480$ min (Eq. 3) $T_{max} \geq 17$ min (Eq. 4)	Corneal, Skin

*Injury TLVs from visible light presume a dark-adapted pupil with additional factors of safety applied. A minimum safety factor of 2 in the spectral radiance L_λ source terms has been included in the ACGIH standard. A minimum safety factor of 5 in the spectral irradiance E_λ source terms has been included in the ACGIH standard. To eliminate this excess conservatism, the requirement should relax the spectral radiance L_λ by multiplying it by a factor of 1⁄2 and the spectral irradiance E_λ by multiplying it by a factor of 1⁄5. Thus, Equations 4a and 4b are subjected to the 2x relaxation factor, while Equation 8b is subjected to the 5x relaxation factor. This reduction does not apply to ultraviolet radiation. Thus, Equations 3 and 4 are not subjected to any relaxation factors.
These limits do not apply to laser exposure (see laser exposure limits). Older versions of the ACGIH TLVs should not be utilized due to substantial differences in hazard functions. These limits do not account for forced chronic solar viewing.
NOTE: Refer to ACGIH 2014 for all equations referenced in this table.

6.8.2.4 Artificial Light Exposure Limits for Ultraviolet (UV) Sources

[V2 6117] The system **shall** fully contain UV sources to prevent crew exposure.

[Rationale: This requirement is intended to prevent ocular injury and skin damage caused by exposure to ultraviolet radiation. Acceptable methods of containment included the use of light-tight structures and enclosures to fully contain the UV at the source and/or UV optical light

obstruction by other means (e.g., screens, shields, filters) before reaching the crew to prevent exposure.]

7. HABITABILITY FUNCTIONS

This section addresses the features of the system required for human occupancy. The specific needs and designs for each feature vary with the type of mission.

7.1 Food and Nutrition

7.1.1 Food Quality and Quantity

7.1.1.1 Food Quality

[V2 7001] The food system **shall** provide the capability to maintain food safety and nutrition during all phases of the mission.

[Rationale: A nutritious, viable, and stable food system that the crew is willing and able to consume is critical for maintaining the health of the crew. The viability of the food system requires not only that food be available for consumption but also that the food has the appropriate nutrient mix to maintain crew health over time. The food is to retain its safety, nutrition, and acceptability for any space flight concept of operations, be it of short or long duration.]

7.1.1.2 Food Acceptability

[V2 7002] The system **shall** provide food that is acceptable to the crew for the duration of the mission.

[Rationale: A viable and stable food system that the crew is willing and able to consume is critical for maintaining the health of the crew. The crew's willingness to consume these nutrients is impacted by the variety and flavor of the food. Consideration is given to provide a variety of food frequency, texture, and flavor while maintaining nutritional integrity as these factors can affect crew food acceptance.

The dynamics of space flight present numerous challenges to food acceptability. A NASA food item measuring an overall acceptability rating of 6.0 or better on a 9-point hedonic scale for the duration of the mission is considered acceptable. The hedonic scale is a quantitative method that is accepted throughout the food science industry as a means to determine acceptability. Further information regarding methods for determining food acceptability can be found in Meilgaard, M., et al. (1999). Food freshness will impact acceptability over time; thus, it is imperative to provide acceptable food initially and a packaging and storage system that will maintain this freshness. Alternatives include growing food or providing basic ingredients and allowing flexibility in their combination and preparation, as well as providing the crew with various condiments to adjust flavors as needed due to the fluid shifts in their sinuses. The ability to *customize with some preference foods and with condiments is important to add some variety and customization, which can help to prevent menu fatigue and support adequate consumption, especially as missions become longer.]*

7.1.1.3 Food Caloric Content

[V2 7003] The system **shall** provide each crewmember with an average of 12,698 kJ (3,035 kcal) per day, else an average energy requirement value is determined using Table 13, EER Equations and applying an activity factor appropriate to the mission gravity and planned level of physical activity.

[Rationale: The metabolic intake provisioning will need verification by analysis to determine energy content of each food item and subsequent menu. The minimum number of calories per day is based on the estimated energy requirements (EER) with an activity factor (AF) of 1.25 (active) as calculated according to Table 13, EER Equations. With this activity factor applied, the average for 84 male crewmembers with an average body mass of 82.9 kg is 12,724 kJ (3,041 kcal). The average for 20 female crewmembers with an average body mass of 65.1 kg is 9,807 kJ (2,344 kcal). Refer also to document JSC 67378 Nutritional Requirements for Exploration Missions up to 365 days, which notes activity factors ranging from 1.0 to 1.25 based on local gravity and exercise capability.]

Table 13—EER Equations

Nominal Metabolic Intake
<u>EER for men 19 years old and older</u> EER (kcal/day) = 662 – 9.53 × Age [y] + AF × (15.9 × Body Mass [kg] + 539.6 × Height [m]) <u>EER for women 19 years old and older</u> EER = 354 – 6.91 × Age [y] + AF × (9.36 × Body Mass [kg] + 726 × Height [m])

7.1.1.4 EVA Food Caloric Content

[V2 7004] For crewmembers performing EVA operations, the food system **shall** provide an additional 837 kJ (200 kcal) per EVA hour above nominal metabolic intake as defined by [V2 7003] Food Caloric Content, of this NASA Technical Standard.

[Rationale: Additional energy and nutrients are necessary during EVA operations, as crewmember energy expenditure is greater during those activities. Consumption of an additional 837 kJ (200 kcal), similar in nutrient content to the rest of the diet, per hour of EVA would allow a crewmember to maintain lean body weight during the course of the mission. This is the metabolic energy replacement requirement for moderate to heavy EVA tasks.]

7.1.1.5 Food Nutrient Composition

[V2 7100] The system **shall** provide a food system with a diet including the nutrient composition that is indicated in the Dietary Reference Intake (DRI) values as recommended by the National

Institutes of Health, with the exception of those adjusted for space flight as noted in Table 14, Nutrient Guidelines for Space Flight.

[Rationale: Macronutrients are nutrients that provide calories for energy and include carbohydrates, protein, and fat. Micronutrients are essential elements the body uses in trace amounts and can include vitamins and minerals. These are necessary to maintain the health of the crew.]

Table 14—Nutrient Guidelines for Space Flight

Nutrients	Daily Dietary Intake*
Vitamin D	25 µg (micrograms)
Vitamin C	Women: 110 mg, Men: 125 mg (milligrams)

** This field is only expressed in metric units of measure.*

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[V2 7005] Requirement merged into [V2 7100].

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[V2 7006] Requirement merged into [V2 7100].

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Table 13 deleted.

7.1.1.6 Food and Production Area Microorganism Levels

[V2 7007] Microorganism levels in the food and production area **shall not** exceed those specified in Table 15, Food Microorganism Levels.

[Rationale: To maintain the health and safety of the crew, it is necessary to control microorganism growth.]

Table 15—Food and Production Area Microorganism Levels

Area/Item	Microorganism Tolerances	
Food Production Area	**Samples Collected**	**Limits**
Surfaces	3 surfaces sampled[a]	3000 CFU/ft^2 (total aerobic count)
Packaging Materials	Before use	3000 CFU per Pouch, Septum, 25 cm^2 or base
Air	1 sample of 320 L monthly	113 CFU/320 L (total aerobic count) (total aerobic count)

Food Product	Factor	Limits
Non-Thermostabilized[b]	Total aerobic count	20,000 CFU/g for any single sample (or if any two samples from a lot exceed 10,000 CFU/g)
Non-Thermostabilized[b] Commercially Sterile Products (thermostabilized and irradiated)	Enterobacteriaceae	100 CFU/g for any single sample (or if any two samples from a lot exceed 10 CFU/g). No detected serious or severe hazard human enteric pathogenic organisms
	Salmonella	0 CFU/g for any single sample
	Yeasts and molds	1000 CFU/g for any single sample (or if any two samples from a lot exceed 100 CFU/g or if any two samples from a lot exceed 10 CFU/g *Aspergillus flavus*)
	No sample submitted for microbiological analysis	100% inspection for package integrity

Notes:
a. Samples collected only on days that food facility is in operation. Additional environmental samples will be collected when there is a one-hour break in activity, or after five hours of continuous work.
b. Food samples considered “finished” products that do not require additional repackaging are tested only for total aerobic counts.

7.1.2 Food Preparation, Consumption, and Cleanup

7.1.2.1 Food Preparation

[V2 7008] The system **shall** provide the capability for preparation, consumption, and stowage of food.

[Rationale: A viable and stable food system that the crew is willing and able to consume is critical for maintaining the health of the crew. Preparation addresses the heating of the food, if necessary, and the use of whatever equipment is required. Consumption relies on utensils or implements such as forks or spoons, a method to open packaging, or a method to rehydrate. Stowage is needed for the food, as well as all the implements for preparation and consumption.]

7.1.2.2 Food Preparation and Cleanup

[V2 7009] The food system **shall** allow the crew to unstow supplies, prepare meals, and clean up for all crewmembers within the allotted meal schedule.

[Rationale: Meal preparation and cleanup activity planning takes into account previous space flight lessons learned, the water delivery and food heating systems, stowage configuration, and desire of the crew to dine together. This is to help ensure that mission goals, objectives, and timelines are not negatively impacted.]

7.1.2.3 Food Contamination Control

[V2 7010] The food storage, preparation, and consumption areas **shall** be designed and located to protect against cross-contamination between food and the environment.

[Rationale: Contamination can occur from a number of sources, including proximity to cross-contamination, toxic materials, and the growth of microorganisms. Food is to be processed properly and stored to control or eliminate microbiological concerns. Furthermore, it is critical for crew physical and psychological health that waste management systems (such as food waste, body waste, personal hygiene, exercise) are separate from food preparation, stowage, and consumption activities to protect from cross-contamination. Space flight lessons learned indicate this has been an issue during Apollo and ISS missions.]

7.1.2.4 Food and Beverage Heating

[V2 7011] The system **shall** provide the capability to heat food and beverages to a temperature appropriate for the given item.

[Rationale: Heating is necessary for the subjective quality of food. Heating food and liquid enhances the palatability of some items, which is important for psychological health, as well as for ensuring that crewmembers eat the food provided. Maintaining the temperature of rehydrated food helps prevent microbial growth. The vehicle is to provide the ability to heat dehydrated and non-rehydrated foods.]

7.1.2.5 Dining Accommodations

[V2 7012] Crewmembers **shall** have the capability to dine together.

[Rationale: Dining together has been shown to support the crew's psychological health and well-being. The food system should account for the volume for all the crewmembers to prepare their meal, gather simultaneously, and accommodate any equipment needed to restrain the food and implements, including utensils necessary for dining. The design and layout of the dining space should be based on a functional task analysis. The specific volume and layout are to meet the requirements defined in section 8, Architecture, in this NASA Technical Standard. Additional guidance for design for habitable volume is provided in Chapter 8 of the HIDH.]

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[V2 7013] Requirement merged into [V2 7064].

7.1.2.6 Food Spill Control

[V2 7014] The system **shall** provide the ability to contain and remove food particles and spills.

[Rationale: The ability to clean spills or food particles in any area of the vehicle helps to minimize contamination of the spacecraft. Contamination of the food system might occur if spills are not contained, and the physical debris of food particles can jeopardize the safety and health of the crew.]

7.1.2.7 Food System Cleaning and Sanitizing

[V2 7015] The system **shall** provide methods for cleaning and sanitizing food facilities, equipment, and work areas.

[Rationale: The ability to clean and disinfect the food system areas helps to minimize microbial contamination of the food system. Contamination of the food system by physical debris can jeopardize the safety and health of the crew.]

7.2 Personal Hygiene

7.2.1 Personal Hygiene Capability

[V2 7016] Personal hygiene items **shall** be provided for each crewmember, along with corresponding system capabilities for oral hygiene, personal grooming, and body cleansing.

[Rationale: Oral hygiene and personal grooming activities are to be accommodated by the system through provision of adequate and comfortable bathing and body waste management facilities as these enhance self-image, improve morale, and increase productivity of the crewmember. Each crewmember is to have personal hygiene provisions, e.g., toothbrush, toothpaste, moistened cloth wipes for body cleansing, deodorant for odor control, oral hygiene, and personal grooming throughout each space mission. Personal hygiene equipment and supplies are to accommodate the physiological differences in male and female crewmembers in microgravity and partial gravity environments. Considerations for crew acceptability should be taken into account as this will impact their overall behavioral performance.]

7.2.2 Body Cleansing Privacy

[V2 7017] The system **shall** provide for privacy during personal hygiene activities.

[Rationale: Certain hygiene functions are to have a degree of privacy, especially in a vehicle in which other crewmembers may be performing other functions simultaneously. Privacy provides

for the psychological well-being of the crew and is to be provided for whole-body and partial-body cleaning and donning and doffing of clothing.]

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[V2 7018] Requirement merged into [V2 7016].

7.2.3 Hygiene Maintainability

[V2 7019] The system **shall** provide an environmentally compatible sanitization method for personal hygiene facilities and equipment.

[Rationale: To remain hygienic, personal hygiene equipment is to be easily cleaned, sanitized, and maintained. Cleaning and sanitizing helps control odor and microbial growth. As part of the overall maintenance of the hygiene facilities, crewmembers are to have readily accessible trash collection for disposable personal hygiene supplies to minimize crew exposure to the used items.]

7.3 Body Waste Management

7.3.1 Body Waste Management Facilities

7.3.1.1 Body Waste Management Capability

[V2 7020] The system **shall** provide the capability for collection, containment, and disposal of body waste for both males and females.

[Rationale: A body waste management system facilitates the clean, efficient, and reliable collection and management of human waste (urine, feces, vomitus, and menses) and associated equipment and supplies.]

7.3.1.2 Body Waste Management System Location

[V2 7021] The body waste management system **shall** be isolated from the food preparation and consumption areas for aesthetic and hygienic purposes.

[Rationale: Contamination can occur from a number of sources, including proximity to cross-contamination and the growth of microorganisms. It is critical for crew physical and psychological health that any interference between body waste management functions and food preparation and consumption be prevented. The isolation of the body waste management system can be achieved by a physical barrier and/or distance from the food system areas to prevent concerns from cross-contamination. Space flight lessons learned indicate this has been an issue during Apollo and ISS missions. For example, due to the close proximity (about 1-foot) of the food system area and body waste management areas, the Apollo crews commented on having

diminished appetites. Additionally, complaints from Skylab included the difficulties during defecation due to the awkward placement of the toilet.]

7.3.1.3 Body Waste Management Privacy

[V2 7022] The system **shall** provide privacy during use of the body waste management system.

[Rationale: Certain hygiene functions are to have a degree of privacy, especially in a vehicle in which other crewmembers may be performing other functions simultaneously. Privacy provides for the psychological well-being of the crew and is to be provided for use of the body waste management system.]

7.3.1.4 Body Waste Management Provision

[V2 7023] Body waste management supplies **shall** be provided for each crewmember and be located within reach of crewmembers using the body waste management system.

[Rationale: Personal hygiene and body waste management supplies such as tissues and towels may need to be accessed rapidly.]

7.3.1.5 Body Waste Accommodation

[V2 7024] The body waste management system **shall** allow a crewmember to urinate and defecate simultaneously without completely removing lower clothing.

[Rationale: Accidental discharge of one or both waste components into the habitable volume is not wanted, and it may be difficult for a human to relax the gastrointestinal control sphincter without relaxing the urinary voluntary control sphincter and vice versa. To minimize impact to crew operations, waste elimination needs to be accomplished with minimal crew overhead, e.g., without completely removing clothing.]

7.3.1.6 Body Waste Containment

[V2 7025] The system **shall** prevent the release of body waste from the body waste management system.

[Rationale: A release of waste into the closed environment of a spacecraft can contaminate the human and risk the initiation or spread of disease but also can contaminate surfaces, materials, and consumables.]

7.3.1.7 Body Waste Odor

[V2 7026] The system **shall** provide odor control for the body waste management system.

[Rationale: Uncontrolled waste-associated odors can have an adverse effect on crew performance and can exacerbate pre-existing symptoms of space motion sickness.]

7.3.1.8 Body Waste Trash Receptacle Accessibility

[V2 7027] Body waste management trash collection **shall** be accessible to and within reach of crewmembers using the body waste management system.

[Rationale: Waste management items that cannot be collected and contained with human waste are to be disposed of immediately after use. Waste management trash collection items are to be within reach of the crewmember so that it is not necessary to egress the waste management restraint system or to access closed compartments.]

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[V2 7028] Requirement merged into [V2 8001].

7.3.1.9 Body Waste Management Maintenance

[V2 7029] All body waste management facilities and equipment **shall** be capable of being cleaned, sanitized, and maintained.

[Rationale: To remain hygienic, body waste management equipment is to be easily cleaned, sanitized, and maintained. Cleaning and sanitizing helps control odor and microbial growth. As part of the overall maintenance of the hygiene facilities, crewmembers are to have readily accessible trash collection for disposable personal hygiene supplies to minimize crew exposure to the used items.]

7.3.1.10 Body Waste Isolation

[V2 7101] For missions greater than 30 days, the system **shall** provide separate dedicated volumes for body waste management and personal hygiene.

[Rationale: Evidence from ISS suggests that locating personal hygiene (e.g., body cleansing, personal grooming) in the same volume as body waste management is impractical and disliked by the crew. Conducting personal hygiene in the Waste and Hygiene Compartment (WHC) limits its use by other crewmembers. Additionally, due to the effects of microgravity, the WHC volume may not be sufficiently clean to support hygiene activities. ISS crewmembers improvise spaces aboard station to conduct personal hygiene that are separate from the WHC volume, which may lead to issues with space utilization and microbial growth due to water liberation. A dedicated space for personal hygiene with appropriate surfaces that limit microbial growth needs to be provided in future vehicles.]

7.3.2 Body Waste Capacity

7.3.2.1 Body Waste Quantities

[V2 7102] The human body waste management system **shall** be capable of collecting and containing the various human body waste as specified in Table 16, Body Waste Quantities, for the expected needs of each mission and task.

[Rationale: Body waste collection is to be performed in a manner that minimizes the possible escape of feces, urine, vomitus, or menses into the habitable volume during microgravity and partial gravity operations, not only due to the high content of microbes present in the feces, but also due to the potential injury to crewmembers and hardware that could result from inadvertent discharge into the cabin. The presence of bacteria in urine is not typical for healthy crew; however, during certain medical conditions, like urinary tract infections, there could be a presence of bacteria, so precautions should consider this.

The body will generate the same quantity of fecal material as is normal in terrestrial circumstances based on food consumption and an individual's metabolism, with individual variables being evacuation frequency and water content. An individual can only evacuate the maximum value at a rate lower than average from limited food consumption inputs. Solid fecal matter is used to describe fecal material that is eliminated as discrete boli and will have surface characteristics that range from relatively dry to sticky depending on the internal water content, which is graphically demonstrated in a Bristol Stool chart derived from Heaton and Lewis, 1997. Diarrheal events are assumed to be in place of normal fecal elimination with the increased quantity based on increased water content and minor amounts of intestinal cellular material. In practice, a waste system should be capable of accommodating fecal consistency across the continuum from solid low water content to diarrheal without allowing escapes of fecal material to the cabin environment. Alternatively, the urine output may be slightly greater or lower in various phases of the mission associated with gravity transitions and fluid intake levels.

Space Adaptation Syndrome (SAS) occurs in up to 70% of first-time fliers (30% of whom may experience vomiting) during the first 48 to 72 hours of microgravity. Also, a possible water landing may cause crewmembers to experience seasickness. Stowage and disposal are to be adequate for a worst-case number of involved crew, severity, and duration of symptoms, as well as the volume of gastrointestinal contents regurgitated. Vomiting and its associated odor, mainly produced by the compound butyric acid, may trigger a wave of bystander nausea and vomiting reaction in adjacent crewmembers in an enclosed space.

It is expected that female crew will have a menstruation cycle approximately every 27-31 days with a discharge of 30-50 mL of menses, with approximately 80% discharged in the first 3-4 days. The frequency and volume will vary from each crewmember. It should not be assumed that a crewmember is hormonally suppressed or that she will not have a change in her cycle or breakthrough bleeding at any point during a mission, thus appropriate capabilities of containing and disposing of menses should be accommodated.

The average values and frequencies of various body waste are representative over the entire mission (launch and return landing) and include occasional occurrences of the maximum values, which are noted in Table 16. Mass and volume values are for the biological material only; however, collection and containment will need to include both the biological material and all hygiene products required for immediate body cleaning after evacuation.

The collection capacity accounts for the healthy adult maximum output during a single event. The human body waste management system should always (nominally) be capable of collecting a maximum fecal event, as it is unknown when a maximum event will occur. The fecal discharge related to gastrointestinal illness (diarrhea) occurs at an increased frequency but is also variable, unpredictable, and largely dependent on etiology. Terrestrial sources of infectious, pathogenic diarrhea such as Rotavirus A and Enterotoxigenic Escherichia coli (ETEC) can produce single-episode volumes as high as 1.5 L. For NASA missions, the preflight crew quarantine period (refer to NASA-STD-3001, Volume 1) is utilized to reduce the risk of infectious disease in-flight. Potential in-mission sources of comparable high-volume diarrhea is from acute radiation events such as SPEs for missions beyond low earth orbit (refer to NASA-STD-3001, Volume 1) and/or food that is not properly stored and prepared (refer sections [V2 7007] Food and Production Microorganism Levels, [V2 7008] Food Preparation, [V2 7010] Food Contamination Control, [V2 7015] Food System Cleaning and Sanitizing and [V2 7021] Body Waste Management System Location). Both of these potential risks need to be addressed as part of whole mission planning. The total collection volume is to accommodate diarrhea caused by likely pathogens or from diarrhea caused by salt/fluid shifts. When a diarrhea event will occur is unknown, so the body waste management system may process the collection differently, e.g., no compaction. The urinary collection system is to be capable of collecting all of the crewmember's output in succession, as well as the simultaneous evacuation of urine and feces with the presence of tissue from either sloughing or menses.]

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[V2 7030] Requirement merged into [V2 7102].

Table 16—Body Waste Quantities

Waste Type	Average Per Event	Maximum Per Event	Duration/Frequency
Feces[a]	Volume: 150 mL (5 fl oz) Mass: 150 g (0.33 lb) Length: 4-23 cm (0.2-9.1 in)	Volume: 500 mL (16.9 fl oz) Mass: 500 g (1.1 lb)	Average of two events per day
Diarrhea[b]	Volume: 500 mL (16.9 fl oz) Mass: 500 g	Volume: 1.5 L (50.7 fl oz) Mass: 1.5 kg	Eight events per day for up to two days
Urine[c]	Volume: 100-500 mL (3.4-16.9 fl oz) Flow Rate: 10-35 mL/s (0.34-1.2 fl oz/s) Mass: 100.7-513.8 g (0.2-1.1 lb)	Volume: 1 L (33.8 fl oz) Flow Rate: 50 mL/s (1.69 fl. oz/s) Mass: 1027.6 g (2.3 lbs)	Average of seven events per day
Vomitus	Volume: 500 mL (16.9 fl oz) Mass: (dependent on stomach contents)	Volume: 1 L (33.8 fl oz) Mass: (dependent on stomach contents)	Eight events per day for up to three days in-flight and post landing
Menses[d] **per cycle**	Volume: 30-50 mL (1.0-1.7 fl oz) Mass: (see footnote)	Volume: 114 mL (3.9 fl oz) Mass: (see footnote)	Approx. 80% released within the first 3-4 days

Note: *(a) Fecal material has a high water content and is assumed to have a specific gravity of 1.0 for purposes of this specification. (b) Diarrhea values include fecal amounts. (c) Normal values for urine's specific gravity are between 1.002 and 1.028 which means that normally, a gallon of urine weighs between 8.362 and 8.579 pounds, or slightly more than water. (d) Menses mass considerations will need to accommodate for the method of collection, i.e., pads and tampons.*

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[V2 7031] Requirement merged into [V2 7102].

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[V2 7032] Requirement merged into [V2 7102].

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[V2 7033] Requirement merged into [V2 7102].

7.3.2.2 Fecal and Urine Elimination Concurrence

[V2 7085] The body waste management system **shall** be capable of collecting and containing all waste during simultaneous defecation and urination.

[Rationale: It is common for individuals to not be able to separate defecation and urination. Body waste collection systems design are to have sufficient capability to capture and contain both.]

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[V2 7034] Requirement merged into [V2 7102].

7.3.2.3 Urine per Crewmember

[V2 7035] The human body waste management system **shall** be capable of collecting and containing urine for either processing or disposal of an average total urine output volume of $V_u = 3 + 2.5t$ liters per crewmember, where t is the mission length in days.

[Rationale: Urine production on the first day after launch, i.e., flight day 0, is 3 L (101.4 fl oz) per crewmember. Urine output may be slightly greater or lower in various phases of the mission associated with gravity transitions and fluid intake levels. Reference Table 16 for maximum output values.]

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[V2 7036] Requirement merged into [V2 7102].

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[V2 7037] Requirement merged into [V2 7102].

7.4 Physiological Countermeasures

7.4.1 Physiological Countermeasures Capability

[V2 7038] The system **shall** provide countermeasures to meet crew bone, muscle, sensorimotor, thermoregulation, and aerobic/cardiovascular requirements defined in NASA-STD-3001, Volume 1.

[Rationale: Exercise is used to maintain crew cardiovascular fitness (to aid in ambulation during gravity transitions, minimize fatigue, maintain cardiovascular health and function, and preserve thermoregulation capacity), to maintain muscle mass and strength/endurance, for recovery from strenuous tasks and confined postures, to rehabilitate minor muscle injuries, and to maintain bone mass. Exercise also has behavioral health benefits. Exercise is to commence as early as possible during the mission and continue throughout all mission phases in accordance with results from the Apollo crew's participation in the June 2006 Apollo Medical Summit (NASA/TM-2007-214755, The Apollo Medical Operations Project: Recommendations to Improve Crew Health and Performance for Future Exploration Missions and Lunar Surface Operations), and recommendations from the 2005 Operational and Research Musculoskeletal Summit. See Appendix A, Reference Documents, for complete citations.]

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[V2 7039] Requirement merged into [V2 8001].

7.4.2 Physiological Countermeasure Operations

[V2 7040] The physiological countermeasure system design **shall** allow the crew to unstow supplies, perform operations, and stow items within the allotted countermeasure schedule.

[Rationale: The ease and the efficiency of the countermeasure system assist in the crew being able to perform their countermeasure activities. The crew needs these activities to maintain health and fitness. It can be expected that daily countermeasure activity will occur.]

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[V2 7041] Requirement moved to section 6.2.4.

7.4.3 Orthostatic Intolerance Countermeasures

[V2 7042] The system **shall** provide countermeasures to mitigate the effects of orthostatic intolerance when transitioning from weightlessness to gravity environments and during G_z (head-to-foot) vehicle accelerations defined in the sustained acceleration limits.

[Rationale: Orthostatic protection is needed to minimize medical and operational impacts. Impacts can include loss of consciousness and decreased cognitive function leading to inability to operate controls, pilot mechanics, and egress vehicle without assistance, thus jeopardizing success or safety of the crew during reentry and landing. Examples of methods that have been successfully used to prevent orthostatic intolerance include fluid/salt loading regimens to restore hydration, lower body (abdomen and leg) compression garments to prevent blood pooling, active cooling to prevent peripheral blood pooling and heat injury, and recumbent crewmember seating to protect cerebral blood flow during G_z (head-to-foot) vehicle accelerations (planetary and lunar) and return to gravity (planetary).]

7.5 Medical

7.5.1 Medical Capability

[V2 7043] A medical system **shall** be provided to the crew to meet the medical requirements of NASA-STD-3001, Volume 1.

[Rationale: NASA-STD-3001, Volume 1, includes Health and Medical Care Standards required to reduce the risk that exploration missions are impacted by crew medical issues and that long-term astronaut health risks are managed within acceptable limits. The Health and Medical Care Standards and associated appendices define the health care, crew protection, and maintenance capability required to support the crew as appropriate for the specific mission destination and duration, as well as for the associated vehicular constraints.]

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[V2 7044] Requirement merged into [V2 8001].

7.5.2 Medical Equipment Usability

[V2 7045] Medical equipment **shall** be usable by non-physician crewmembers in the event that a physician crewmember is not present or is the one who requires medical treatment.

[Rationale: Medical equipment is to be simple and easy to use and require minimal training so that non-medical personnel can administer care to ill or injured crewmembers. Medical equipment also is to have consistent interfaces to assist in crew usability.]

7.5.3 Medical Treatment Restraints

[V2 7046] The capability **shall** exist to position and restrain a patient, care provider, and equipment during treatment.

[Rationale: Patient restraints are to be capable of preventing the motion of arms and legs, allow stabilization of the head, neck, and spine, and provide attachment to the spacecraft or habitat. Care provider restraints are to allow the care provider to remain close to the patient to administer treatment but should be easily removable or allow movement to access nearby equipment. Equipment restraints are to be able to safely restrain large items such as medical kits, as well as individual items.]

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[V2 7047] Requirement merged into [V2 7064].

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[V2 7048] Requirement merged into [V2 7064].

7.5.4 Deceased Crew

[V2 7049] Each human space flight program **shall** provide the capability to handle deceased crewmembers.

[Rationale: Despite screening, health care measures, and safety precautions, it is possible for crewmembers to die during a mission, particularly on extended duration missions. Problems that can threaten the health and safety of remaining crewmembers include grief, mission delays, and contamination. Facilities and plans for handling deceased crewmembers that are socially, biologically, and physically acceptable are to be established during system development. The plan needs to consider the following factors: minimizing risk to surviving crewmembers, potential forensics collection, biohazard containment (via pressurized suit or human remains

containment unit) and legal jurisdiction which will involve working with other agencies (such as the Federal Bureau of Investigation) and international partners (via treaties).]

7.6 Stowage Provision and Accessibility

7.6.1 Provision

Stowage provision includes stowage volume (e.g., containers, racks, shelves), and stowage restraints. Defined stowage space is needed to accommodate items including but not limited to crew personal items, crew hygiene and body waste supplies, medical supplies, cleaning supplies, and food. Some stowed items are removed from stowage, used, and then returned to the provided provisions/location. Other items are temporarily removed from stowage, relocated to another use location, and much later stowed. Stowage design for crew access needs must be defined through iterative crew task analysis and include frequency of use, stowed item criticality, operational use/need timeline and priority, interference from/to adjacent or parallel tasks, spacesuit or PPE configuration, anthropometry (e.g., reach, clearance). For operational efficiency, design of stowage provisions should be integrated with inventory management, labeling, and operational nomenclature.

7.6.1.1 Stowage Provisions

[V2 7050] The system **shall** provide for the stowage of hardware and supplies, to include location, restraint, and protection for these items.

[Rationale: Some stowed items are removed from stowage, used, and then returned to the provided provisions/location. Other items are temporarily removed from stowage, relocated to another use location, and much later stowed.]

7.6.1.2 Personal Stowage

[V2 7051] The system **shall** provide a stowage location for personal items and clothing.

[Rationale: Stowage locations for personal items and clothing aids crew morale and well-being. When integrated with inventory management, labeling, and operational nomenclature, the stowing of and access to these personal items should be accomplished efficiently.]

7.6.1.3 Stowage Location

[V2 7052] All relocatable items, e.g., food, EVA suits, and spare parts, **shall** have a dedicated stowage location.

[Rationale: To maintain a high level of efficiency in crew operations, it is important to locate items within easy reach of their point of use or consumption. Although difficult to achieve completely, all efforts are to be made to provide stowage for items manifested and flown. An important consideration is the need to keep the translation pathways clear and protect the

volume necessary for the crew to execute their tasks safely and efficiently. Stowage is not to hinder the access to any emergency equipment.]

7.6.1.4 Stowage Interference

[V2 7053] The system **shall** provide defined stowage locations that do not interfere with crew operations.

[Rationale: Having defined stowage locations supports efficient operations and helps prevent the stowage system from interfering with operations such as translation and vehicle control. Care is to be taken when designing the stowage system so that clear translation can occur in the event of an emergency. To maintain a high level of efficiency in crew operations, it is important to locate items within easy reach of their point of consumption.]

7.6.1.5 Stowage Restraints

[V2 7054] The system **shall** provide the capability to restrain hardware, supplies, and crew personal items that are removed or deployed for use as defined by crew task analysis.

[Rationale: Stowed and deployed items are to be restrained so that they are secure for crew use and prevent uncontrolled movement causing injury, damage, or inefficient task performance under expected conditions for acceleration, vibration, or crew contact. Restraints must also be designed to facilitate operations in expected gravity environment. For example, in microgravity, restraints should be retainable in open or loosened position to facilitate stow/unstow of items during stowage operations. Stowage restraints help protect the crew from injury and equipment from damage or loss, and ensure that stowed or deployed items remain where required during operations and crew tasks.]

7.6.2 Accessibility

Accessibility means having the ability to reach and retrieve objects with relative ease. The following subsections define requirements for implementing this feature.

7.6.2.1 Priority of Stowage Accessibility

[V2 7055] Stowage items **shall** be accessible in accordance with their use, with the easiest accessibility for mission-critical and most frequently used items.

[Rationale: Items should be stowed to promote efficient retrieval and operations.]

7.6.2.2 Stowage Operation without Tools

[V2 7056] Stowage containers and restraints **shall** be operable without the use of tools.

[Rationale: To maximize the use of crew time, the stowage system is to permit crew access and reconfiguration without the use of tools.]

7.6.2.3 Stowage Access while Suited

[V2 7057] The stowage system **shall** be accessible by a suited crewmember.

[Rationale: The stowage system must be designed to include features that allow a suited crewmember to access, open, close, or manipulate stowed items. This means the integrated system must accommodate suit constraints and volumetric requirements. This applies to normal as well as contingency operations.]

7.6.3 Identification System

[V2 7058] The stowage identification system **shall** be compatible with the inventory management system.

[Rationale: Space Shuttle and ISS experience has shown that stowage management and identification—the knowledge of the quantity, location, and type of each supply—is crucial for mission planning and maintaining crew productivity. Quantity and location are not the only aspects of stowage identification. Stowage, labeling, inventory tracking, and operational nomenclature are also to be considered when developing an integrated system.]

7.7 Inventory Management System

7.7.1 Inventory Tracking

[V2 7059] The system **shall** provide an inventory management system to track the locations and quantities of items (including hazardous trash) throughout the mission.

[Rationale: Space Shuttle and ISS experience has shown that inventory/stowage management—the knowledge of the quantity and location of each type of supply—is crucial for mission planning and maintaining crew productivity. Quantity and location are not the only aspects of inventory tracking. Stowage, labeling, and operational nomenclature are also to be considered when developing an integrated system.]

7.7.2 Inventory Operations

[V2 7060] The system **shall** be designed to allow inventory management functions to be completed within the allotted schedule.

[Rationale: The inventory management system is to be efficient, and the amount of time required by the crew to perform the functions of the system minimized. A flexible system allows for changes in stowage locations or quantities any time during missions. Lessons learned in past

space flight have indicated that past inventory operations have exceeded the allocated time required to accomplish the tasks. This can interfere with other expected tasks.]

7.7.3 Nomenclature Consistency

[V2 7061] The nomenclature used to refer to the items tracked by the inventory management system **shall** be consistent with procedures and labels.

[Rationale: It is imperative that space flight operations personnel, including all ground controllers and crewmembers, communicate using common nomenclature that unambiguously and uniquely defines all hardware and software items. This nomenclature is also to be common among all operational products, including commands, procedures, displays, planning products, reference information, system handbooks, system briefs, mission rules, schematics, and payloads operations products.]

7.7.4 Unique Item Identification

[V2 7062] Items that need to be uniquely identified **shall** have a unique name.

[Rationale: Unique names for inventory items assist in the location and clear identification of the items. This promotes efficiency and reduces the likelihood of mis-selection of items for tasks. This also assists to minimize training.]

7.7.5 Interchangeable Item Nomenclature

[V2 7063] Items within the inventory management system that are identical and interchangeable **shall** have identical nomenclature.

[Rationale: Names for inventory items assist in the location and clear identification of the items. This promotes efficiency and reduces the likelihood of mis-selection of items for tasks.]

7.8 Trash Management System

7.8.1 Provision

7.8.1.1 Trash Accommodation

[V2 7064] The system **shall** provide a trash management system to contain, mitigate odors, prevent release, and dispose of all expected trash.

[Rationale: All wet and dry waste, including food, sharp items, biological, chemical, and radioactive materials should be planned for and accommodated within the system for the duration of the mission until planned disposal. Task analysis should identify waste generating tasks, waste types and quantities, biological content, environmental conditions (including gravity), odor, and other relevant task conditions. Odors may be mitigated by neutralizing,

removing, or containing. Considering potential health effects to the crew, waste containment systems should control microbial growth and not allow inadvertent escape of biological or chemical contaminants and should protect crew from inadvertent injury from sharp items and medical equipment. A good practice is to separate and isolate hazardous and non-hazardous waste containment, such as body waste and food packaging waste. Hazardous waste containers are to be clearly and visibly identified with text and/or symbolic labeling. If multiple types of hazardous waste are accumulated in a single container, the outermost containment label indicates the highest level of hazard (e.g., toxicity, biohazard) contained. Trash stowage volumes and locations are to be defined to ensure stored waste does not interfere with crew operations. The design should consider how crew will operate the system in their intended environment: How will crew prevent waste particles from escaping in microgravity; How will the containment system withstand changing pressure environment; What is the planned duration of containment until trash can be removed from the vehicle.]

7.8.1.2 Trash Volume Allocation

[V2 7065] Trash stowage volumes **shall** be allocated for each mission.

[Rationale: The trash plan defines the types and quantities of trash expected during mission operations. Trash buildup occurs, especially on missions where there is no expendable vehicle to carry away the trash, or capability to jettison or recycle the waste. Dedicated trash stowage volumes and locations are needed and are to be coupled with appropriate packaging and containment. The volume and mass allocations for body waste are referenced in Table 16 of requirement [V2 7102] Body Waste Quantities.]

7.8.1.3 Trash Stowage Interference

[V2 7066] The system **shall** provide defined trash stowage that does not interfere with crew operations.

[Rationale: This requirement is intended to prevent the trash system from interfering with normal operations such as translation and vehicle control. Design requirements are to ensure that the trash system does not interfere with translation during emergency events. As well, in an effort to maintain a high level of efficiency in crew operations, it is important to locate trash receptacles within easy reach of their point of use.]

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[V2 7067] Requirement merged into [V2 7064].

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[V2 7068] Requirement merged into [V2 7064].

7.8.2 Labeling of Hazardous Waste

[V2 7069] The hazard response level (HRL) of all liquids, particles, gases and gels **shall** be labeled on the outermost containment barrier in location(s) visible to crew.

[Rationale: Hazard response labeling informs the crew of appropriate personal protective equipment (PPE) and clean-up response in the event of an unintended release. Assessment of liquids, gels, gasses, and particles used in the habitable volume are performed by NASA JSC Toxicology, BioSafety, Materials, and Environmental Control teams to determine appropriate HRL. System and hardware developers can submit information to NASA per JSC-27472, Requirements for Submission of Data Needed for Toxicological Assessment of Chemicals and Biologicals to be Flown on Manned Spacecraft. The requirements for HRL labeling are defined in JSC-27260, Standard Flight Decal Catalog.]

7.9 Behavioral Health and Sleep

7.9.1 Sleep Accommodation

[V2 7070] The system **shall** provide volume, restraint, accommodations, environmental control (e.g., vibration, lighting, noise, and temperature), and degree of privacy for sleep for each crewmember, to support overall crew health and performance.

[Rationale: The sleep accommodation requirements depend primarily on the gravity environment and the mission duration. However, in microgravity environments, restraints are provided to secure blankets and maintain positioning, with a range from knees-to-chest to full-body stature. Evidence from short- and long-duration missions and other relevant isolated, confined, and extreme environments suggests that environmental factors such as noise, temperature, vibration, and light inhibit sleep and impact well-being in space. Individual crew preferences vary, so individual control of the sleep environment is necessary to ensure adequate sleep and maintain physical and behavioral well-being during missions. Examples of sleep accommodations provided to each crewmember include clothing, bedding, ear plugs, light blockers, eye masks, etc. (See section 8.5, Restraints and Mobility Aids, in this NASA Technical Standard.)]

7.9.2 Behavioral Health and Privacy

[V2 7071] For long duration missions (>30 days), individual privacy facilities **shall** be provided.

[Rationale: Isolation, confinement, mission task demands, social density, and other associated aspects of space flight can lead to stress, which tends to increase with mission duration. Therefore, privacy is a countermeasure needed to protect the behavioral health of the crew, particularly in space flight vehicles with a relatively smaller volume. Terrestrial literature has further shown that greater distance between workstations is associated with improved job performance relative to smaller distances and that increased privacy is related to decreased emotional exhaustion. Providing private accommodations for crew to accommodate sleep and

social retreat will allow for improved sleep quality and completion of tasks with reduced distractions and will allow for crew to temporarily withdraw for emotional restoration. Tasks that require privacy, such as private medical or psychological conferences, will also need to be facilitated by accommodations for visual and auditory privacy.]

7.9.3 Partial-g Sleeping

[V2 7073] The system **shall** provide for horizontal sleep surface areas for partial-g and 1-g environments.

[Rationale: The sleeping area volume is to accommodate crew body sizes in all gravity environments. Partial-g, i.e., lunar (1/6) and Mars (1/3) gravity, defines the orientation of the volume. Orientation and body support (e.g., cushioning) should be considered in partial-g environments.]

7.10 Clothing

7.10.1 Clothing Quantity

[V2 7074] Clean, durable clothing **shall** be provided in quantities sufficient to meet crew needs.

[Rationale: Requirements are to be based on acceptable definitions of "clean" and "durable." Requirements are then to include the number of days that an individual item of clothing can be worn before laundering or disposal and, for laundered clothing, the lifetime of the clothing item. Clothing should be designed so it can be donned and doffed in all situations without assistance from other crewmembers.]

7.10.2 Clothing Exclusive Use

[V2 7075] Clothing **shall** be provided for each individual crewmember's exclusive use.

[Rationale: Requirements for exclusive clothing use are to include considerations for individual stowage areas, clothing identification (particularly if clothing is laundered), sizing, and individual preference accommodation.]

7.10.3 Clothing Safety and Comfort

[V2 7076] Clothing **shall** be comfortable in fit and composition, for the environment, e.g., temperature and humidity, in which it will be worn.

[Rationale: Requirements for clothing types are to be based on anticipated crew activities, e.g., exercise, maintenance, lounging, work, etc., and gravity environments, e.g., very loose clothing and shoes would be inappropriate in a microgravity environment. Layering of clothing may accommodate temperature and personal preferences. (See Figure 2, Crew Health Environmental Limits, [V2 6012] Crew Health Environmental Limits and [V2 7041] Environmental Control.)

Clothing design is also dependent on the range of crew sizes as defined in the physical characteristics database. (See section 4.1 Physical Data Sets in this NASA Technical Standard.) Clothing material should be assessed as stated in NASA-STD-6016. Material selection should include evaluation for material degradation that produces lint or fuzz.]

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[V2 7077] Requirement merged into [V2 7074].

7.11 Housekeeping

7.11.1 Accessibility for Cleaning

[V2 7079] The system **shall** provide sufficient volume to access areas that need to be cleaned and perform housekeeping duties.

[Rationale: Access to areas that need to be cleaned include physical access (e.g., panels and covers can be easily removed) and the provision of sufficient volumes for cleaning activities and associated hardware. The full-size range of personnel with appropriate cleaning tools and equipment is to be able to access all areas for routine cleaning. Areas such as vents that need to be cleaned regularly need to be easily accessible. Complex access procedures (e.g., disassembling panels, disconnecting alarms) add time and frustration to task performance. Fixed equipment should not have to be unsecured and moved for routine cleaning. Inaccessible areas are to be closed off to prevent the accumulation of trash, dirt and dust particulates.]

7.11.2 Particulate Control

[V2 7080] The system **shall** be designed for access, inspection, and removal of particulates that can be present before launch or that can result from mission operations.

[Rationale: Manufacture, assembly, or other operations in a terrestrial or partial-g environment may accumulate residue and debris. This residue may then contaminate the spacecraft during flight or reduced-gravity environments. System development specifications are to ensure that crews can access residue accumulations for removal.]

7.11.3 Microbial Surface Contamination

[V2 7081] The system **shall** provide surfaces that are microbiologically safe for human contact.

[Rationale: Microbiologically safe surfaces are essential to prevent infection and mitigate risk to crew health and performance. Assessing the microbiological safety of internal surfaces relies primarily on the enumeration and identification of viable, medically significant microorganisms (bacteria and fungi) that are known to cause disease. Historically, microbial concentrations on internal surfaces of crewed spacecraft have been controlled by the selection of materials that do not promote microbial growth and can be cleaned/disinfected in-flight. Medical significance of

microorganisms and allowable levels of microorganisms are set based on guidance from the JSC Microbiology Laboratory. Program level requirements for surface contamination include considerations for factors such as intended uses, vehicle architecture, and mission duration. Considerations should be taken for scenarios where there is a period of dormancy or uncrewed operations.]

7.11.4 Surface Material Cleaning

[V2 7082] The system **shall** contain surface materials that can be easily cleaned and sanitized using planned cleaning methods.

[Rationale: Program requirements are to be established so that surface materials such as highly textured materials are assessed for this feature.]

7.11.5 Cleaning Materials

[V2 7083] The system **shall** provide cleaning materials that are effective, safe for human use, and compatible with system water reclamation, air revitalization, waste management systems, and spacesuits.

[Rationale: Program requirements are to be established so that cleaning materials are assessed for these features. Effective cleaning materials leave a cleaned surface ready for use without the need for additional cleaning. For example, an effective window cleaning material leaves the window with no accumulation, streaking, or any other artifact that could interfere with the use of the window (photography or piloting tasks). On the other hand, cleaning material used on a dining table could be considered effective even with the presence of streaks or accumulation, as long as the surface is safe on which to prepare, serve, and consume food.]

7.11.6 Condensation Limitation

[V2 6058] The system **shall** prevent condensation persistence on surfaces within the vehicle.

[Rationale: The presence of free water can promote the growth of microbial organisms, which poses a hazard to human health. The system is to provide controls and mitigation steps to prevent the formation of condensate on internal surfaces for a length of time, thus preventing microbial growth to unacceptable levels. Initial microbial concentration, the probable types of organisms, the porosity of the surface materials, and exposure can affect the acceptable persistence of the condensate based upon crew health risk mitigation. Examples of moisture buildup from previous space flight missions that resulted in fungal growth include non-insulated cold surfaces and designed operations, which moisten surfaces (such as wetting a cloth) without appropriate drying. Condensation on a non-ventilated surface will be difficult to dry. Current ISS requirements provide some flexibility in allowable condensate persistence for areas determined to have minimal crew health risk.]

7.12 Recreational Capabilities

[V2 7084] The system **shall** provide individual and team-oriented recreational capabilities for the crew to maintain behavioral and psychological health.

[Rationale: Appropriate recreational facilities depend on the nature and duration of the mission. Program development requirements are to provide time and resources for psychological assessment of crew needs. The system design is to include recreational facilities, materials, and operational accommodations identified in these assessments.]

8. ARCHITECTURE

Architecture is defined as the arrangement and configuration of the functional areas where the crew lives and works. This includes any items necessary for translation, restraints and mobility aids, hatches, windows, and lighting. For detailed requirements to accommodate the physical characteristics of the crew, see section 4, Physical Characteristics and Capabilities, in this NASA Technical Standard. Accommodations for the specific functions that occur within the architecture of the habitat are addressed in section 7, Habitability Functions, in this NASA Technical Standard. Environmental qualities of the architecture are in section 6, Natural and Induced Environments.

See Appendix C for definitions of Pressurized Volume, Non-habitable Volume, Dedicated Equipment Work Volume and Habitable Volume.

8.1 Volume

8.1.1 Volume Allocation

[V2 8001 The system **shall** provide the defined habitable volume and layout to physically accommodate crew operations and living.

[Rationale: The architectural layout of space for living and working should be designed to provide defined locations and volumes that allow for expected crew activities, including mission operations, habitability functions, and translation. Required volume is a function of the number of crew, number of mission and contingency days, and the crew activities. Design and layout of functional volumes are guided by function and task analysis, as well as iterative process of design and evaluation. Task attributes such as operational flow, frequency, dependencies, compatibility, interference, equipment, crew postures and gravity environment should be considered in the functional layout and interfaces. Tasks that are sensitive or incompatible with other activities, such as food prep, body self-inspection and cleansing, and use of the lavatory, should be separated or isolated to avoid contamination or detrimental impacts to performance, health, or well-being. Private self-inspection following use of the lavatory will impose additional volume needs in microgravity or very low fractional environments to ensure that waste has separated from the body and clothing and not recirculated in adverse trajectories – something that is less necessary in 1g or higher fractional gravities. Longer mission duration will increase

functional volume needs for accommodation of stowage, increased volume for exercise equipment including exercise performance, medical treatment facilities and equipment; as well as crew sleep, recreation and privacy for behavioral health. Volume, size, and layout of medical treatment facilities and equipment will need to consider number of crewmembers, level of care, mission duration, crew activities, and the likelihood that multiple crewmembers may require simultaneous medical attention. For spacecraft volume design methodology and best practices, refer to SA-16-156, Level II JSC CMO HMTA Position on NHV and Internal Layout Considerations for Exploration Missions; NASA/TP-2014-218556; NASA/SP-2010-3407, section 8.2, Overall Architectural Design, and JSC 63557, Net Habitable Volume Verification Method.]

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[V2 8002] Requirement merged into [V2 8001].

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[V2 8003] Requirement merged into [V2 8001].

8.1.2 Functional Arrangement

[V2 8005] Habitability functions **shall** be located based on the use of common equipment, interferences, and the sequence and compatibility of operations.

[Rationale: Design for any system, function, or activity is to be based on the logical sequence and smooth flow of activities that are to occur. Generally, the most efficient layout is to place functions adjacent to each other when they are used sequentially or in close coordination. There are some limitations to this general rule, however. Adjacent positions are not to degrade any of the activities within the stations, nor is the positioning to degrade any of the activities in surrounding stations. General adjacency considerations, beyond simple activity flow, include transition frequency, sequential dependency, support equipment commonality, physical interference, traffic interference, privacy, confidentiality, noise output and sensitivity, lighting, vibration, simultaneous use or adjacent use by multiple crewmembers, and contamination.]

8.1.3 Interference

[V2 8006] The system **shall** separate functional areas whose functions would detrimentally interfere with each other.

[Rationale: Co-location of unrelated activities can degrade operations, resulting in increased workload and operational delays. This consideration will be difficult to meet in a small volume, but every effort is to be made to separate functions and capabilities that could operationally conflict with each other or that produce environmental conditions that conflict with other tasks, e.g., glare, noise, vibrations, heat, odor.]

8.2 Configuration

Configuration refers to the visual aides that inform crewmembers about their spatial orientation and location within the spacecraft. This section describes requirements for consistent visual cues for orientation and location within and among modules.

8.2.1 Spatial and Interface Orientation

[V2 8007] The system **shall** have consistent spatial and interface orientations relative to a defined vertical orientation.

[Rationale: The human working and living position is to be established with respect to a defined local vertical, especially when there is no gravity cue that identifies the up or down orientation. To promote efficient performance and avoid disorientation or errors, the system designer should define the spatial and interface directional orientation using design features such as visual orientation cues (e.g., labeling), orientation of work surfaces, positioning of displays and controls, etc. Maintaining a consistent orientation of interfaces minimizes crewmember rotational realignments needed to perform tasks that have directionally dependent components such as reading labels and displays. Inconsistent and varied display and control orientations may contribute to operational delays or errors. Given the complexity of some operations (e.g., piloting), a single orientation for all controls, displays, and labels may not be possible; but the design is to minimize crewmember repositioning to efficiently perform a task. This requirement is meant to ensure that all equipment at an interface is aligned with respect to the crewmember's head so that an operating crewmember only needs to adjust body orientation slightly in pitch and yaw at a workstation but does not need to adjust body orientation in roll. Orientations are to be consistent within a given functional volume where crew may interface with multiple different elements. Separate functional volumes (e.g., lab module, cargo module, observation cupola) may each have their own local orientation, different from other volumes, but internally consistent to support crew interfaces.]

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[V2 8008] Requirement merged into [V2 8007].

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[V2 8009] Requirement merged into [V2 8007].

8.2.2 Location Identifiers

[V2 8010] A standard location coding system **shall** be provided to uniquely identify each predefined location within the system.

[Rationale: Location coding provides a clear method of referring to different locations within the vehicle habitat and serves as a communication and situational awareness tool when traversing the vehicle or unstowing/stowing equipment.]

8.2.3 Location Aids

[V2 8011] The system **shall** provide aids to assist crewmembers in locating items or places within the system and orienting themselves in relation to those items or places.

[Rationale: Crewmembers need visual cues to help them quickly adjust their orientation to a local vertical position. When adjacent workstations have vertical orientations differing by 45 degrees or greater, visual demarcations need to be provided to prevent inadvertent use of the adjacent workstation elements.]

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[V2 8012] Requirement deleted.

8.3 Translation Paths

Translation paths are to be designed so traffic flow does not detrimentally interfere with other unrelated activities such as sensitive spacecraft control, routine servicing, experimentation, eating, sleeping, and relaxation. Pathways should be clear of hazards (e.g., protrusions, entanglements (cables, hoses), free-floating equipment) to avoid crew injury or equipment damage. Pathways that dead-end or may have unpassable hazard (i.e., open ignition source) should be sized to allow crewmembers to turn around and retreat.

8.3.1 Intravehicular Translation Paths

[V2 8013] The system **shall** provide intravehicular activity (IVA) translation paths that allow for safe and unencumbered movement of suited and unsuited crew and equipment.

[Rationale: Translation paths are the defined volumes reserved for safe and efficient movement of crew and equipment for nominal, contingency, or emergency operations. Pathway size and shape is based on task analysis to take into account needs and constraints such as the location, type, and level of activity that will occur in functional areas or workstations (e.g., movement within recreation area, cargo translation between vehicle and module, temporary rack rotation); the crew movement postures (e.g., upright or prone position, pushing or pulling equipment); the type of equipment being translated; the number of crew (simultaneous or sequential flow); the configuration of crew (unsuited, suited unpressurized, suited pressurized, PPE). Translation paths are to be designed so traffic flow does not detrimentally interfere with other unrelated activities such as sensitive spacecraft control, routine servicing, experimentation, eating, sleeping, and relaxation. Lessons learned from the ISS indicate that translation paths around the ISS eating area have disrupted crew rest and relaxation required during meals. Pathways should be clear of hazards (e.g., protrusions, entanglements (cables, hoses), free-floating equipment) to

avoid crew injury or equipment damage. Pathways that dead-end or may have unpassable hazard (i.e., open ignition source) should be sized to allow crewmembers to turn around and retreat. Slip, trip, and fall hazards must be taken into account for any translation paths that may be used in full or partial gravity. This requirement also applies to pressurized tunnels, which allow for translation between docked pressurized elements, and should be designed to allow for static or dynamic forces and variations of alignment (such as uneven terrain) without imparting forces onto the elements.]

8.3.2 Emergency Escape Paths

[V2 8014] The system **shall** provide unimpeded and visible emergency escape routes commensurate with the hazard analyses and response concept.

[Rationale: The system developer should plan emergency escape routes early in the design process. This begins with analysis to identify system hazards, time-to-effect of hazards or emergencies, and crew tasks which define the system design needs and constraints. The routes should be free of obstructions (snags, protrusions, stowed items, etc.), clearly marked to guide the way to safety (e.g., with color-coded strip lighting, photoluminescent decals, etc.), illuminated for emergency tasks, and require a minimal number of operations for passage (such as awkward turns or hatch operations). Pathway markings should be visible during power loss. If multiple escape paths lead to different areas depending on the emergency, the correct pathway should be made clear to crew. An open hatchway is insufficient identification of an egress route. When considering time required, account for the entire route the crew would need to take to get to safety as well as time to access and carry necessary equipment. When sizing the route, designers need to consider the dimensions of the users, including suits and special protective/survival equipment, and the number of concurrent users, including possible rescue personnel.]

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[V2 8015] Requirement merged into [V2 8013].

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[V2 8016] Requirement merged into [V2 8013].

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[V2 8017] Requirement merged into [V2 8013].

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[V2 8018] Requirement merged into [V2 8013].

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[V2 8019] Requirement merged into [V2 8014].

8.3.3 Assisted Ingress and Egress Translation Path

[V2 8020] The system **shall** provide translation paths that accommodate the ingress and egress of a crewmember assisted by another crewmember.

[Rationale: An injured, deconditioned, or incapacitated crewmember may be unable to ingress or egress a vehicle on their own and may need assistance from another person or the aid of a device. An ingress or egress translation path is to accommodate the crewmember being assisted, the assisting personnel, and any necessary equipment, e.g., medical equipment. The conditions (e.g., ingress/egress orientation with respect to gravity environment, all planned pressurized or unpressurized suits, number of personnel) and constraints (e.g., egress time) for assisted ingress and egress are to be determined by concept of operation and task analysis.]

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[V2 8021] Requirement merged into [V2 8020].

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[V2 11002] Requirement merged into [V2 8013].

8.3.4 EVA Translation Path Hazard Avoidance

[V2 11005] EVA translation paths **shall** be free from hazards.

[Rationale: Safety is paramount for all EVA tasks. When translation paths and mobility aids are properly provided, they can reduce the hazards associated with colliding with hardware, intruding into keep-out zones, contacting sharp edges and burrs, or contacting contaminated surfaces. Without predefined translation paths and carefully located mobility aids, items or equipment not intended as mobility aids can be damaged from induced loads, such as grabbing, pushing, and pulling.]

8.4 Hatches and Doorways

See Appendix C for definitions of Hatch, Hatch Cover, Hatchway, Door and Doorway.

8.4.1 Operability

8.4.1.1 Hatches and Door Operation without Tools

[V2 8022] Hatches and doors **shall** be operable on either side by a single crewmember without the use of tools in expected gravity conditions, orientations, suit configurations, and operational configurations.

[Rationale: Hatch operation includes equalizing pressure, unlatching/opening, and latching/closing the hatch to enable translation through or isolation of pressurized volumes. Hatches should be designed for single crew operation since they may be in a small volume or in an escape route and need to be quickly opened by the first crew there. Tool use for manual pressure equalization and opening/closing hatches is prohibited to avoid hatch operation delays or failures. Lost or damaged tools may prevent hatches from being opened/closed resulting in loss of crew (LOC) or loss of mission (LOM). Gravity conditions, hatch orientations, and suit configurations should be considered in hatch design and operations as they impact crew task posture, strength motion, deconditioning, and safety. When there are program/project needs for hatch and door tool provisions, an exception or waiver to this document may be necessary.

8.4.1.2 Unlatching Hatches

[V2 8023] Hatches **shall** require two distinct and sequential operations to unlatch.

[Rationale: Inadvertent hatch opening, and subsequent cabin depressurization would be catastrophic. Requiring two separate, distinct operations helps to ensure that the hatch will not be unlatched through accidental contact.]

8.4.1.3 Hatch and Door Operating Times

[V2 8024] For nominal operations, hatches and doors **shall** be operable by a single crewmember in no more than 60 seconds, from both sides of the hatch.

[Rationale: Hatch operation includes unlatching/opening or latching/closing the hatch. Excessively long operating times can delay crews on both sides of a hatch, which would prevent ingress or egress. The hatch operating requirement of 60 seconds is based on engineering judgment related to easily operable hatch design without complicating hatch design and includes time for a deconditioned crewmember to operate hatch. This does not preclude a program/project from implementing more strict design requirements. For guidance regarding emergency escape time, see requirement [V2 8014] Emergency Escape Paths in this NASA Technical Standard.]

8.4.1.4 Hatch and Door Operating Force

[V2 8025] The forces required to operate each crew interface for the hatches and doors **shall** be within the crewmember strength defined by requirement [V2 4104] Crew Operational Loads for the worst-case pressure differential and anticipated encumbering equipment and clothing.

[Rationale: All crewmembers are to be able to operate hatches and doors. Designing operating forces to the strength of the weakest crewmember ensures the crew can perform activities related to safety and to LOM. Determination of anticipated worst-case parameters can be made through a detailed task analysis. For example, in 1997, a Progress collided with Mir and caused a cabin depressurization; the crew were unable to close the hatch due to the force of the rushing air.]

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[V2 8026] Requirement merged into [V2 8022].

8.4.2 Hatchway and Doorway Design

8.4.2.1 Hatchway Size and Shape

[V2 8027] Hatchways and doorways **shall** be sized and shaped to accommodate all planned translations, including unrestricted passage of a suited crewmember and crewmembers carrying cargo or equipment.

[Rationale: A pressurized-suited crewmember represents a situation where the crewmember's size is enlarged in many dimensions by virtue of the suit. Should a situation arise where the crewmember needs to move through hatchways and doorways while suited, especially in an emergency situation, the hatchways and doorways are to be large enough for the crewmember to pass safely and efficiently. Planned tasks include all nominal and planned contingency tasks. Also, reconfiguration of a spacecraft may require crewmembers to transport potentially large pieces of equipment across hatchways and doorways. Hatchway size should also consider the capability for a rescuing crewmember to be able to transport an incapacitated crewmember without being hampered by inadequate hatchway or doorway sizes. Hatchways and doorways may be designed to accommodate translation of robotic agents, but they should still accommodate crewmembers and their equipment.]

8.4.2.2 Pressure Equalization across the Hatch

[V2 8028] Each side of each hatch **shall** have manual pressure equalization capability with its opposite side, achievable from that side of the pressure hatch by a suited or unsuited crewmember.

[Rationale: Air pressure is to be equalized on either side of a hatch to safely open the hatch. In some vehicle failure scenarios, non-manual methods for pressure equalization may fail. Manual

pressure equalization enables hatch opening regardless of vehicle status. This capability does not need to be physically located on the hatch if task analysis supports a different location.]

8.4.2.3 Visibility across the Hatch

[V2 8029] The system **shall** provide a window for direct, non-electronic visual observation of the environment on the opposite side of the hatch.

[Rationale: Direct visual observation of the environment on the opposite side of the hatch allows the crew to determine the conditions or obstructions for safety purposes, such as the presence of fire or debris. Windows do not have the failure modes associated with cameras and display systems that may not be operable during emergencies when most needed. While cameras or other sensors may be used to supplement the situational awareness afforded by a window, those systems alone do not meet the intent of this requirement. The minimum window field of view and what environmental conditions must be detected for crew and vehicle safety will be determined via task analysis, and verification should be done through the observation of the volume on the opposite side of the hatch in both viewing directions (internal to external and vice-versa for crew and vehicle safety) via a flight-like hatch window in flight-like configuration to determine if the objects or conditions identified via task analysis can be detected. Hazards may be assessed to determine if sensors, cameras and procedural processes can be considered in lieu of windows for certain vehicles/modules not meant for habitation.]

8.4.3 Hatch and Door Design

8.4.3.1 Hatch, Hatch Cover, and Door Interference

[V2 8030] When opened, hatches, hatch covers, and doors **shall** allow for unrestricted flow of traffic.

[Rationale: Open hatches, with or without hatch covers, and doors are not to protrude into translation space and inhibit the safe and effective movement of both the crewmembers and any equipment they need to move from one location to another. In addition, open hatches, with or without hatch covers, and doors are to allow for a clear emergency translation pathway.]

8.4.3.2 Hatch Closure and Latching Status Indication

[V2 8031] Pressure hatches **shall** indicate closure and latching status on both sides of the hatch.

[Rationale: Indication of hatch closure and latch status on both sides of the hatch allows both ground personnel (launch pad) and crewmembers to verify that each hatch is closed and latched. For cases in which multiple latches must close in order to secure a hatch, this requirement applies to the system-level latched status of the hatch. By providing both closure and latch position status, proper security of the hatch can be verified. Hatch closure implies that the hatch is in proper position to be latched.]

8.4.3.3 Hatch Pressure Indication

[V2 8032] Pressure hatches **shall** indicate, viewable from both sides of the hatch, pressure differential across the hatch.

[Rationale: Indication of pressure difference on both sides of the hatch allows both ground personnel and crewmembers to see the changes in pressure across the hatch and to know when the pressure difference is low enough to safely open the hatch. Use of numerical values, color, or other cues can be used to indicate when it is safe to operate a hatch. Direct, non-electronic pressure difference measurement and display on both sides of the hatch will allow both ground personnel and flight crew to see a direct measurement and view the changes in pressure across the hatch to know when the pressure difference is low enough to safely open the hatch, without reliance on mental calculations or being subject to failure modes of an electronic display. This function is especially needed during an emergency. Direct measurement display does not need to be directly on the hatches but must be viewable by the crew at the hatch worksite while operating the hatch.]

8.4.4 No Drag-Throughs

[V2 8101] Hatchways **shall** be clear of drag-throughs.

[Rationale: During emergencies, hatchway may need to be closed quickly; therefore, no item should inhibit their function. Hatchways should remain clear of items, including, but not limited to, cargo, cables, and wires. For example, during a cabin depressurization, the crew will need to immediately close a hatch, which cannot be inhibited, like what occurred on Mir when there was resupply vehicle collision with the U.S. habitat module, and the crew could not quickly close the hatch because of the obstructions in the hatchway.]

8.5 Restraints and Mobility Aids

In reduced gravity and dynamic acceleration environments, restraints are needed by crew to position and stabilize themselves and protect from injury. Restraints are also needed to react to operational forces, such as during hatch opening/closing operations. The design and placement of crew restraints begins with crew task and worksite analysis to determine physical task factors such as crew body positions (e.g., workstation, sleep, personal hygiene, medical treatment), suit configuration (e.g., suited or unsuited, pressurization, gloves, boots), movement action (e.g., single- or two-handed operation), movement direction, range of motions, force, duration, etc.

8.5.1 Restraints for Crew Tasks

[V2 8033] The system **shall** provide restraints for expected crew operations.

[Rationale: In reduced gravity and dynamic acceleration environments, restraints are needed by crewmembers to position and stabilize themselves and protect from injury across a wide range of operations as identified by task analysis. Restraints are also needed to react to

operational forces, such as during hatch opening/closing operations. The design and placement of crew restraints begins with crew task and worksite analysis to determine physical task factors such as gravity conditions (e.g., micro, partial, or 1-g), crew body positions (e.g., workstation, sleep, personal hygiene, medical treatment), operational configuration (e.g., suited or unsuited, pressurization, gloves, boots, PPE), movement action (e.g., single- or two-handed operation), movement range and direction, force, duration, etc. Worksite analysis is an extension of the task analysis to further describe the expected physical interactions between the crew and their system interfaces. Restraints may be intentionally designed and dedicated to specific task(s) or may be planned for multi-purpose use such as designing cargo straps to also be used as foot restraints during cargo operations. Restraints should not impede task performance. Adjustable restraints may be appropriate to accommodate variations in crew anthropometry or range of motion. If task sensitivity or duration requires crew to be stabilized for an extended period of time, design consideration should be given to avoid pain or fatigue which can be detrimental to task performance. Body posture and joint angles should also be considered in the design and placement of restraints. Suited posture, joint angles, and range of motion are unique and should be factored into the design of suit restraints for EVAs, airlock, etc. Standardizing the form factor of restraints will help crew to easily identify and use intentional restraints. In the absence of intentional restraints, ISS experiences have shown that crew will use convenient physical features to stabilize themselves. Hardware failures have occurred due to unplanned use of features that were not designed to withstand loads or repeated use.]

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[V2 8034] Requirement merged into [V2 8033].

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[V2 8035] Requirement merged into [V2 8033].

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[V2 8036] Requirement merged into [V2 8033].

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[V2 8037] Requirement merged into [V2 8033].

8.5.2 Restraint and Mobility Aid Standardization

[V2 8038] Restraints and mobility aids **shall** be standardized, clearly distinguishable, and located to aid crewmembers in starting or stopping movement, changing direction or speed, or translating equipment.

[Rationale: Restraints and mobility aids such as handholds and foot restraints allow crewmembers to efficiently move from one location to another in microgravity, as well as reduce

the likelihood of inadvertent collision into hardware that may cause damage to the vehicle or injury to the crew. Without predefined restraints and mobility aids, personnel may use available equipment that may be damaged from induced loads. By standardization of the restraints and mobility aids, reduction in crew training can occur, and the aids can be easily identified when translating inside or outside the spacecraft. Commonality among visual cues is important so that crews can easily distinguish intended restraints and/or mobility aids from equipment or structures that may be damaged by the application of crew-induced loads. During emergencies, crews need to be able to quickly discern restraints and/or mobility aids from the surrounding structures. Visual cues such as color coding may aid in this function.]

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[V2 8039] Requirement deleted.

8.5.3 Mobility Aid for Assisted Ingress and Egress

[V2 8040] Mobility aids **shall** be provided for the assisted ingress and egress of suited or unsuited crewmembers.

[Rationale: Crewmembers needing assistance (including suited crew, in either pressurized or unpressurized suits, or unsuited crew) may be unable to ingress or egress spacecraft and may also be in a constrained position that requires assistance from another person. Moving the crew may include ingress from EVA or ingress/egress to/from another spacecraft from EVA or any vehicle or module to which a spacecraft is docked. Mobility aids should be employed to protect crewmembers from a fall when descent from height is necessary to reach surface for EVAs. Assisting crew may need mobility aids not only for translating but also for stabilization during the translation of the incapacitated crewmember. Note that the term "mobility aids" is not intended to indicate a specific design solution; rather, the intent is to ensure that physical design of vehicles accommodate operations such as those described here. Mobility aids may refer to specially designed hardware (e.g., handholds) or the use of existing features of the system for mobility (e.g., a handle on a hatch), in which case additional testing and verification may be required.]

8.5.4 Unassisted Ingress, Egress, and Escape Mobility Aids

[V2 8041] Mobility aids **shall** be provided for ingress, egress, and escape of crewmembers without assistance from other crew or ground personnel.

[Rationale: In off-nominal situations, the crew may need to ingress, egress, or escape unassisted while suited or unsuited. Because a suited crewmember has limited maneuverability, mobility aids allow a more safe and efficient ingress and egress of the vehicle and escape from the pad. Mobility aids should be employed to protect crewmembers from a fall when descent from height is necessary to reach surface for EVAs. Note that the term "mobility aids" is not intended to indicate a specific design solution; rather, the intent is to ensure that physical design of vehicles accommodate operations such as those described here. Mobility aids may refer to specially

designed hardware (e.g., handholds) or the use of existing features of the system for mobility (e.g., a handle on a hatch), in which case additional testing and verification may be required.]

8.5.5 Mobility Aid Provision

[V2 8042] Mobility aids **shall** be provided to support all expected suited and unsuited tasks.

[Rationale: Mobility aids must support all IVA tasks, which may be suited or unsuited. Mobility aids for EVA operations must be provided along the expected translation paths of suited crewmembers at an interval that accommodates the suited crewmember's reach. Mobility aids such as handholds and foot restraints allow crewmembers to efficiently move from one location to another in microgravity, as well as reduce the likelihood of inadvertent collision into hardware that may cause damage to the vehicle or injury to the crew. Early experience in the Skylab program showed the problems of movement in microgravity. Stopping, starting, and changing direction all require forces that are best generated by the hands or feet. Appropriately located mobility aids make this possible. Mobility aids are to be designed to accommodate a pressurized-suited crewmember by providing clearance, non-slip surfaces, and noncircular cross sections. Without predefined mobility aids, personnel may use available equipment that may be damaged from induced loads. Because of the limited maneuverability of a suited crewmember, mobility aids are required to allow crewmembers to safely and efficiently ingress and egress the vehicle, as well as to protect crewmembers from a fall when descent from height is necessary to reach surface for EVAs.]

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[V2 11003] Requirement merged into [V2 8042].

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[V2 11012] Requirement merged into [V2 8033].

8.5.6 Human Transport Vehicle Restraint Provision

[V2 8102] The human transport vehicle, when operating in fractional (lunar or planetary) gravity, **shall** provide a restraint for each person inside the vehicle.

[Rationale: On surfaces with reduced gravity, the need for a physical restraint (e.g., lap belts or over-the-shoulder) within the human transport vehicle is necessary to prevent injury to the crew. Injury could occur from the continued motion of the crew when the vehicle is accelerating in any direction. Restraints help crewmembers remain in position and within the confines of the vehicle, while also preventing crewmembers from colliding with the vehicle's features or walls. It is not sufficient to rely on crewmembers to brace themselves in the vehicle. Each rider should have individual restraints to reduce the chances of injury.]

8.6 Window

Windows are an integral part of many aspects of space flight operations with respect to their location, optical properties, fields of view, and protection. The minimum critical design parameters for windows to support these operations and tasks are size, color balance, haze, transmittance, wavefront quality, reflectance, material inclusions, surface defects, ambient illumination, visual obstructions, e.g., mounting for optical hardware and cameras, internal and external contamination, the position of windows on the spacecraft, and the distance, position, and orientation of the user relative to a window.

8.6.1 Window Provisioning

[V2 8043] The system **shall** provide windows with unobstructed fields of view for expected crew operations.

[Rationale: Windows provide direct, non-electronic, through-the-hull viewing and are essential to mission safety and success, as well as to maintaining crew psychological and physical health and safety. They support crew photography (a primary on-and-off duty activity of onboard crews), provide situational awareness of the external environment, facilitate piloting and robotic operations, and permit safe viewing through hatches. Windows also permit stellar navigation, vehicle anomaly detection and inspection, and environmental and scientific observations. Windows do not have the failure modes associated with cameras and display systems that may not be operable during emergencies when most needed. The following hardware is not considered an obstruction to the window field of view: (1) hardware designed and intended to protect and cover windows; (2) hardware used in conjunction with piloting (i.e., Head's Up Display (HUD), Crew Optical Alignment System (COAS), or other similar equipment); (3) the outer mold line and hull structure of the vehicle, other windows, and window mullions; and (4) instrumentation applied within 13 mm (0.5 in) of the perimeter of the viewing area.]

8.6.2 Window Optical Properties

[V2 8045] System windows **shall** have optical properties commensurate with crew task needs.

[Rationale: System windows are required to have the optical properties necessary to prevent degradation of visual acuity and optical performance. JSC-66320, Optical Property Requirements for Glasses, Ceramics, and Plastics in Spacecraft Window Systems, specifies optical properties for different types of system windows according to their associated tasks (the uses to which they will be put). These optical properties provide system windows with the minimal optical performance necessary to support those tasks and permit the retrieval of imagery through windows so that the retrieved images are not blurred, degraded, or distorted. This requirement applies to all types of windows provided by the system.]

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[V2 8046] Requirement merged into [V2 8043].

8.6.3 Window Light Blocking

[V2 8049] Each system window **shall** provide a means to prevent external light from entering the crew compartment, such that the interior light level can be reduced to 2.0 lux at 0.5 m (20 in) from each window.

[Rationale: External illumination can interfere with internal spacecraft operations such as crew sleep and onboard still and motion imaging, particularly if the illumination causes glare. Shades and shutters block external illumination from entering the habitable volume through windows. This requirement applies to all types of windows provided by the system.]

8.6.4 Window Accessory Replacement/Operation without Tools

[V2 8050] System window accessories designed for routine use **shall** be operable by one crewmember and be removable or replaceable without the use of tools.

[Rationale: System window accessories such as window covers, shades, and filters should be designed to be easily installed and removed using their attachment features without additional tools. The ability to remove, open, replace, or close window accessories efficiently ensures proper use of the hardware and appropriate protection for the windows and the crew. This requirement applies to all types of windows provided by the system.]

8.7 Lighting

Lighting affects a crew's visual ability, health, and safety. This section defines requirements for adequate lighting, prevention of distractive lighting, compatibility of lighting with sleep cycles, and informative lighting.

8.7.1 Illumination Levels

[V2 8051] The system **shall** provide illumination levels to support the range of expected crew tasks.

[Rationale: A wide range of crew tasks is expected to be performed within the vehicle during all phases of flight. The required lighting levels vary, depending on the task being performed. For instance, cabin reconfiguration after orbit insertion may require simultaneous reading of labels and checklists, crew translation, mechanical assembly, and manual control at a variety of vehicle locations, each of which requires sufficient lighting without blockage from crew and equipment in transit. Similarly, rendezvous and proximity operations may require general cabin darkening for out-the-window viewing but sufficient lighting for crew translation and manual control. A single type of lighting at a single illumination level is insufficient to support all tasks; therefore, both general and task illumination are necessary.]

8.7.2 Exterior Lighting

[V2 8052] The system **shall** provide exterior lighting to aid the crew in assembly, maintenance, navigation, rendezvous and docking, ingress and egress, EVA operations, and external task operations.

[Rationale: External operations are performed on a routine basis, especially when vehicles are located on planetary surfaces. The types of operations vary greatly, from supporting the crew in conducting assembly and maintenance and in the locating of the vehicles and habitats to general wayfinding and navigation, to surface geology and other science. Lighting types and illumination levels appropriate to the expected tasks are necessary to accomplish mission objectives. Planetary surface illumination and reflection are to be addressed; these vary, depending on the planetary body selected for the mission, as well as the location on that planetary body.]

8.7.3 Emergency Lighting

[V2 8053] The system **shall** provide emergency lighting for crew egress and/or operational recovery in the event of a general power failure.

[Rationale: Emergency lighting is a part of the overall lighting system for all vehicles. It allows for crew egress and/or operational recovery in the event of a general power failure. The emergency lighting system is to be automatically activated to allow operators and other occupants of a vehicle to move to a safe location and allow efficient transit between any inhabited location and designated safe haven(s). Efficient transit includes appropriate orientation with respect to doorways and hatches, as well as obstacle avoidance along the egress path.]

8.7.4 Lighting Chromaticity

[V2 8059] Interior and exterior lighting intended for operational environments requiring human/camera color vision **shall** have a chromaticity that falls within the chromaticity gamut for white light for the Correlated Color Temperature (CCT) range of 2700 K to 6500 K as defined by ANSI C78-377, Electric Lamps—Specifications for the Chromaticity of Solid State Lighting Products.

[Rationale: The ability to make variable customized lighting spectra adds risk that an implementer will come up with a light that meets some color constraints but fails to create an environment that appears white or will create one in which cameras have trouble operating. ANSI C78-377 (see NEMA C78.377) forces the definition of white to be a color gamut along the blackbody locus of the International Commission on Illumination (CIE) 1931 chromaticity chart. For variable CCT systems, it is important that humans and cameras within that environment see color correctly and interpret the light as white light anywhere along the color range of white light as defined by ANSI C78-377. Exceptions to this requirement include conditions that do not require color vision such as window operations and sleep environment, as determined by a task analysis.]

8.7.5 Lighting Color Accuracy

[V2 8060] Interior and exterior lighting intended for human operational environments requiring photopic vision accuracy **shall** have a score of 90 ±10 on a color fidelity metric that is appropriate for the utilized lighting technology, as designated by the Color Fidelity Metric (Rf) defined by IES TM-30, Method for Evaluating Light Sources Color Rendition methodology.

[Rationale: Accurate representation of the colored environment impacts several areas of concern for human performance and behavior, including critical color matching tasks (e.g., matching litmus strips to cue cards) and the representation of skin tone and biological material (e.g., for health diagnostics). Rapid advancements in modern lighting technology such as solid-state lighting require careful consideration of the proper color fidelity metric selection for the evaluation of color rendition properties of a light source. Color Rendering Index (CIE CRI Ra) is the first established color fidelity metric; it is widely used but it is an improper metric for sources below CCT of 5000 K as well as sources with peaked spectra such as solid-state technology. Color Quality Scale (CQS) improves upon the methodology of CRI to more accurately describe color hue and saturation shifts. For a complete suite of color rendition metrics, the IES TM-30 method is recommended. TM-30 provides a color fidelity metric (Rf) that is analogous to CRI Ra but more accurate, a color gamut index (Rg) to describe color saturation, and a color vector graphic for visualization of hue and saturation changes with respect to a reference source. IES TM-30 has an extensive toolset for evaluation of the ability of a lamp to properly render colored materials within an environment. This toolset is advanced from the Color Quality Scale and provides a means to evaluate the performance of a lighting system with any material, given its spectral reflectance, allowing for tailoring for program-specific critical colored surfaces. It is highly recommended that this tool be included in any lighting performance specification. Situations to which this requirement applies should be determined by a task analysis.]

8.7.6 Physiological Effects of Light (Circadian Entrainment)

[V2 8055] The system **shall** provide the levels of light to support the physiological effects of light in accordance with Table 17, Physiological Lighting Specifications.

[Rationale: Light is both a stimulant and the most effective signal for entraining and resetting the circadian clock. The magnitude of these effects depends primarily on the intensity, spectrum, timing and duration of light. Lighting Systems should provide proper light to promote alertness during wake and work hours, promote sleepiness during the 'pre-sleep' time, and promote or avoid circadian resetting when required. Failure to provide adequate lighting during wake will lead to suboptimal alertness and performance. Failure to provide appropriate lighting during pre-sleep will lead to prolonged sleep latency, reduced sleep duration and reduced sleep quality, and suppression of the pineal 'darkness' hormone melatonin. Failure to provide an adequate 24-hour light-dark cycle (or a 24-hour and 40 minute cycle for Mars missions) will lead to misalignment between the circadian clock and the rhythms the clock controls including, but not limited to, sleep, performance, mood, metabolism, endocrine function, immune function,

reproductive function and glucose and lipid regulation. It is important to note that in the absence of an appropriate light signal, the circadian rhythm will IMMEDIATELY begin to mis-align, which is why it is necessary to require lighting sufficient for entrainment on short-duration missions. Failure to provide appropriate circadian resetting in response to a shift schedule will also lead to circadian misalignment.]

Table 17 —Physiological Lighting Specifications

Lighting Levels at Cornea	Melanopic EDI Lux	Melanopic DER	Peak Wavelength	NOTE
General Ambient Lighting	≥ 250	≥ 0.7	480 ± 30nm (blue-enriched)	1, 2
Crew Pre-Sleep	8 +/- 2	≤ 0.3	≥ 550nm (blue-depleted)	1, 3

NOTES:
1. Melanopic EDI is measured at the cornea in the vertical plane. Both EDI and DER thresholds for each lighting condition must be met.
2. During all waking hours, the white light must be 'blue-enriched' to maintain alertness and entrainment of the circadian pacemaker to a 24-hour day and facilitate schedule shifting when required.
3. During scheduled pre-sleep, the white light must be 'blue-depleted' to reduce alertness and prepare the brain for sleep.
4. Melanopic Equivalent Daylight Illuminance (EDI, in melanopic lux) and melanopic Daylight Equivalent Ratio (DER, no units) shall be calculated according to the most recent version of the International Commission on Illumination (CIE) International Standard: CIE S 026:2018. System for Metrology of Optical Radiation for ipRGCInfluenced Responses to Light. CIE, Vienna (DOI: 10.25039/S026.2018)
5. CIE Position Statement on Non-Visual Effects of Light. 2019 https://cie.co.at/files/CIE%20Position%20Statement%20-%20Proper%20Light%20at%20the%20Proper%20Time%20(2019)_0.pdf
6. Brown, T.; Brainard, G.; Cajochen, C.; Czeisler, C.; Hanifin, J.; Lockley, S.; Lucas, R.; Munch, M.; O'Hagan, J.; Peirson, S.; Price, L.; Roenneberg, T.; Schlangen, L.; Skene, D.; Spitschan, M.; Vetter, C.; Zee, P.; Wright Jr., K. Recommendations for Healthy Daytime, Evening, and Night-Time Indoor Light Exposure. Preprints 2020, 2020120037 (doi: 10.20944/preprints202012.0037.v1).

8.7.7 Lighting Controls

[V2 8056] Lighting systems **shall** have on-off controls.

[Rationale: Controls for turning lighting on and off within each module allow crewmembers to see the effect of changes to lighting controls without changing their location. Easy access to the controls is necessary. Light sources are to be capable of being turned completely off and returned to on. This control allows for the execution of operations that require observation through windows or photography and for crew functions such as sleep.]

8.7.8 Lighting Adjustability

[V2 8057] Interior lights **shall** be adjustable (dimmable) from their maximum output level to their minimum luminance.

[Rationale: Interior lighting is to be adjustable to permit the crew to use out-the-window views when there is little external light, for example, during rendezvous, and to allow the selection of lower light levels when crewmembers are resting.]

8.7.9 Glare Prevention

[V2 8058] Both direct and indirect glare that causes discomfort to humans or impairs their vision **shall** be prevented.

[Rationale: Eye discomfort can occur and visual performance can be negatively affected by glare. If a light source within the observer's field of view provides much more luminance than its surroundings (higher range of contrast) and occupies a significant portion of the field of view, it may act as a direct glare source. If the reflection of a light source from a surface within the field of view provides an area whose luminance greatly exceeds that of its surroundings, it may act as a reflected (indirect) glare source. The types of tasks expected to be performed are to be considered, as well as the location where the tasks occur, whether they are internal or external to the vehicle, and whether they are on or off a planetary surface. Glare should first be eliminated though proper consideration and arrangement of the spacecraft internal system architectural environment, including the lighting system, window design, architectural surface treatments, and backlit displays. In situations where this perfect arrangement is not possible, mitigating measures such as lighting source baffles, window shades, and computer monitor glare shields can be used.]

9. HARDWARE AND EQUIPMENT

This section provides requirements applicable to the design of hardware and equipment. Requirements in this section apply to all hardware and equipment with which the crew interfaces—from large and complex systems such as ISS racks, to small items such as tools, drawers, closures, restraints, mobility aids, fasteners, connectors, clothing, and crew personal equipment. Hazard minimization is accomplished through hardware design, and design of interior components which crew may encounter, through nominal mission activities, including maintenance operations, and anticipated off-nominal events.

Equipment refers to items such as tools used to accomplish a task or activity. Equipment is a type of hardware, and therefore this term is sometimes used interchangeably with hardware.

Hardware refers to individual components of equipment, including but not limited to fasteners, panels, plumbing, switches, switch guards, and wiring. This term is sometimes used interchangeably with equipment.

9.1 Standardization

9.1.1 Crew Interface Commonality

[V2 9001] Hardware and equipment performing similar functions **shall** have commonality of crew interfaces.

[Rationale: The intent of this requirement is to ensure commonality and consistency within a given human space flight program. This facilitates learning and minimizes crew error.]

9.1.2 Differentiation

[V2 9002] Hardware and equipment that have the same or similar form but different functions **shall** be readily identifiable, distinguishable, and not be physically interchangeable.

[Rationale: The intent of this requirement is to avoid potential confusion crewmembers may experience that can lead to errors when items with similar form are not readily identifiable or physically distinguishable.]

9.1.3 Routine Operation

[V2 9003] Worksites **shall** be designed to provide rapid access to needed tools and equipment for routine/nominal operations.

[Rationale: Good design of systems and equipment can reduce the amount of time to perform many routine tasks, e.g., food preparation, maintenance, and inventory management. Having to retrieve, use, and stow tools for the routine/nominal operation of systems, hardware, and equipment can be especially cumbersome and burdensome for routine tasks. The ability to perform operations with promptness helps ensure proper use.]

9.2 Training Minimization

[V2 9004] Hardware and equipment with which crew interact **shall** minimize the time required for training.

[Rationale: Generally, designers can minimize training by following requirements dictated in this NASA Technical Standard under section 9.1, Standardization, and section 10, Integrated Human Performance and Crew Interfaces. However, a specific system may have characteristics that could minimize training requirements. For example, an upgrade in technology of an existing system could maintain the same interface. This could be defined in system requirements and would minimize the need for additional training.]

9.3 Hazard Minimization

9.3.1 Mechanical Hazard Minimization

9.3.1.1 Design for Crew Safety

[V2 9101] The system **shall** be designed to minimize physical hazards to the crew.

[Rationale: Physical hazards to the crew, such as moving mechanical parts, entrapment, potential energy, loose item projectiles, sharp edges, pinch points, equipment handling, fluid/gas release, etc., are to be mitigated throughout the system design. Safety hazard analyses are to be performed to identify all known hazards to crew and corresponding hazard controls. Hazards

can be avoided by designing out the hazard, controlled by the use of safety devices, or mitigated by providing warnings, or through procedures and training. These are arranged in descending order of preference; designing out the hazard is the most preferred, while relying on procedures or training is the least preferred.]

9.3.1.2 Mechanical Hazard

[V2 9005] Systems, hardware, and equipment **shall** protect the crew from moving parts that may cause injury to the crew.

[Rationale: Known mechanical hazard sources can be defined in a requirement. Consistently moving equipment is easy to identify and guard. Infrequent or unpredictable movement may be a less obvious hazard. If possible, system requirements are to identify potential sources of unpredictable or infrequent movement and spell out specific guarding requirements for these systems.]

9.3.1.3 Entrapment

[V2 9006] Systems, hardware, and equipment **shall** protect the crew from entrapment (tangles, snags, catches, etc.).

[Rationale: This applies to items with which the crew will come into direct contact. Entrapment can occur in places where loose cables or equipment items block passageways or where crewmembers purposely fasten motion restraints (seat belts and shoulder harnesses, foot restraints, tethers, etc.). Entrapment can also occur from protrusions or openings that snag body parts or personal equipment. For example, if holes are small, then fingers may be entrapped. Larger holes, on the other hand, allow free movement. Crewmembers are likely to be under time-critical conditions when they need to evacuate or return to safety. If possible, requirements are to focus on those situations.]

9.3.1.4 Potential Energy

[V2 9007] Hardware and equipment **shall** not release stored potential energy in a manner that causes injury to the crew.

[Rationale: Requirements are to identify all known sources of stored potential energy. As with all hazards, this can be mitigated by designing out the hazard, the use of safety devices, providing warnings, or through procedures and training. These mitigations are arranged in descending order of preference: designing out the hazard is the most preferred, while relying on procedures or training is the least preferred.]

9.3.1.5 Protection from Projectiles and Structural Collapse

[V2 9008] Hardware mounting and habitat enclosures **shall** be configured such that the crew is protected from projectiles and structural collapse in the event of sudden changes in acceleration or collisions.

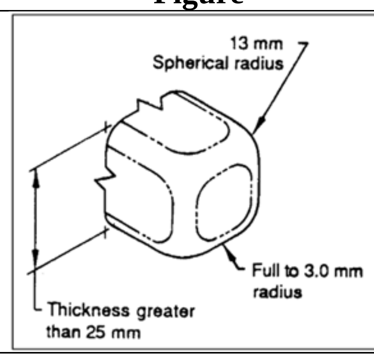
[Rationale: Chances for crew survivability in otherwise catastrophic conditions can be greatly increased by attention (early in the design process) to structure and mounting designs such that the crew habitable volume remains intact and free of secondary projectiles.]

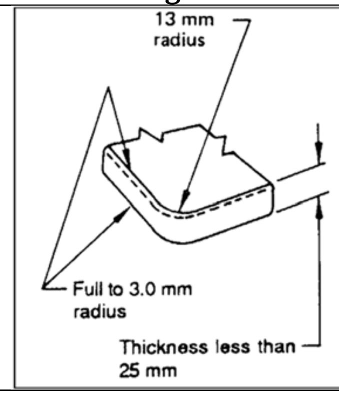
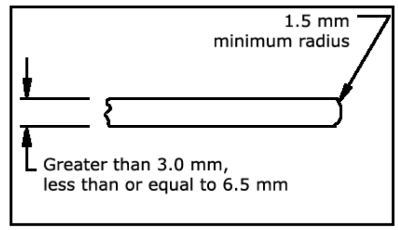
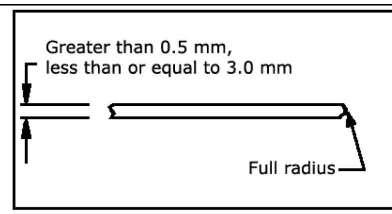
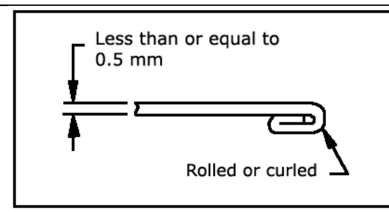
9.3.1.6 Sharp Corners and Edges – Fixed

[V2 9009] Corners and edges of fixed and handheld equipment to which the bare skin of the crew could be exposed **shall** be rounded as specified in Table 18, Corners and Edges.

[Rationale: Sharp corners and edges in passageways, maintenance areas, stowage compartments, or workstations present hazardous conditions and are to be avoided. Also, hand-held items such as tools present a hazard to the crew. In addition to potential hazards from IVA exposure, EVA exposure to sharp surfaces could damage suit integrity. This requirement applies to bare skin. Gloves and clothing may protect skin; however, some clothing or equipment items may be more vulnerable to tears and cuts; separate requirements need to be established for those items. The crew may be exposed to items manufactured by a variety of companies, and this requirement is to be reflected in requirements for all of them.]

Table 18—Corners and Edges

Material Thickness (t)	Minimum Corner Radius	Minimum Edge Radius	Figure
t > 25 mm (t > 1 in)	13 mm (0.5 in (spherical))	3.0 mm (0.120 in)	

Material Thickness (t)	Minimum Corner Radius	Minimum Edge Radius	Figure
6.5 mm < t < 25 mm (0.25 in < t < 1 in)	13 mm (0.5 in)	3.0 mm (0.125 in)	
3.0 mm < t < 6.5 mm (0.125 in < t < 0.25 in)	6.5 mm (0.26 in)	1.5 mm (0.06 in)	
0.5 mm < t < 3.0 mm (0.02 in < t < 0.125 in)	6.5 mm (0.26 in)	Full radius	
t < 0.5 mm (t < 0.02 in)	6.5 mm (0.26 in)	Rolled, curled, or covered to 3.0 mm (0.120 in)	

9.3.1.7 Protection from Functionally Sharp Items

[V2 9010] Functionally sharp items **shall** be prevented from causing injury to the crew or damage to equipment when not in use.

[Rationale: Functionally sharp items are those that, by their function, do not meet the requirement for exposed corners and edges, e.g., syringes, scissors, and knives. These items are to be prevented from causing harm when not in nominal use. Capping sharp items is one way of doing this.]

9.3.1.8 Sharp Corners and Edges - Loose

[V2 9011] Corners and edges of loose equipment to which the crew could be exposed **shall** be rounded to radii no less than those given in Table 19, Loose Equipment Corners and Edges.

[Rationale: The force (and resulting damage) in contact with fixed items depends on the mass and speed of the crewmember. The damage from loose items, however, depends on the weight of the item. For example, a person running into a fixed clipboard will cause more damage than if the clipboard were thrown at that person. Therefore, the corners and edges of a loose item do not have to be as rounded as a fixed item. Although hand-held items are loose, they are squeezed, and forces can be high. Therefore, hand-held items are to meet the edge and corner rounding requirements of fixed items as referenced in [V2 9009] Sharp Corners and Edges–Fixed, in this NASA Technical Standard.]

Table 19—Loose Equipment Corners and Edges

Equipment Mass		Minimum	Minimum
At Least (kg (lb))	Less Than (kg (lb))	Edge Radius (mm (in))	Corner Radius (mm (in))
0.0 (0.0)	0.25 (0.6)	0.3 (0.01)	0.5 (0.02)
0.25 (0.6)	0.5 (1.1)	0.8 (0.03)	1.5 (0.06)
0.5 (1.1)	3.0 (6.6)	1.5 (0.06)	3.5 (0.14)
3.0 (6.6)	15.0 (33.1)	3.5 (0.14)	7.0 (0.3)
15.0 (33.1)	--	3.5 (0.14)	13.0 (0.5)

9.3.1.9 Burrs

[V2 9012] Exposed surfaces **shall** be free of burrs.

[Rationale: Burrs are manufacturing artifacts or can occur during a mission as a result of maintenance or assembly operations. Burrs cause damage to equipment and skin. They are to be removed as a part of the manufacturing process; or, if it is likely that they will be created during a mission, a means is to be provided to eliminate crew exposure to the burrs.]

9.3.1.10 Pinch Points

[V2 9013] Pinch points **shall** be covered or otherwise prevented from causing injury to the crew.

[Rationale: Pinch points can cause injury to the crew but may exist for the nominal function of equipment, i.e., equipment panels. This may be avoided by locating pinch points out of the reach of the crew or by providing guards to eliminate the potential to cause injury.]

9.3.1.11 Equipment Handling

[V2 9016] All items designed to be carried or removed and replaced **shall** have a means for grasping, handling, and carrying while wearing the most encumbering equipment and clothing anticipated.

[Rationale: Grasping, gripping, and moving hardware using hardware features that are not intended to be handles can damage the hardware or slip away and injure the crewmember or damage surrounding hardware. This can be prevented by designing obvious features that are intended for grasping, gripping, or moving the item. Manual Materials Handling(MMH) guidance can be used for identifying the appropriate MMH method based on equipment size, shape, weight (mass), gloved/ungloved, 1- or 2-person carry, etc. Pressurized and unpressurized suit biomechanics also needs to be considered for any tasks performed while suited as referenced in [V2 11024] Ability to Work in Suits, in this NASA Technical Standard.]

9.3.2 Temperature Exposure

Deleted:

[V2 9014] Requirement merged into [V2 9102] and [V2 9103].

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[V2 9015] Requirement merged into [V2 9102] and [V2 9103].

The following temperature exposure requirements for bare skin [V2 9102] Skin/Tissue Damage Temperature Limits, and [V2 9103] Pain/Non-Disabling Injury Skin Temperature Limits, which are summarized in Figure 14, Summary of Bare Skin Exposure Standards Temperature Ranges, and Table 20, Summary Table of Bare Skin Exposure Standards Temperature Ranges/Limits.

These temperatures are temperature limits for the outer layer of the skin. The calculation of the material being touched, in relation to its temperature and the contact time, will result in a skin temperature at the end of the contact period. This temperature must be compared to the values in Table 20 to determine the need for control(s). Duration of skin contact with an object that is beyond the skin limits ensures the skin temperature is within the nominal range, may be used as a control. Refer to tables 22-25 for equations and sample calculations for different materials that may be used to determine the duration of skin contact. Refer to ASTM C1057-17, Standard Practice for Determination of Skin Contact Temperature from heated surfaced using a mathematical model and Thermesthesiometer.

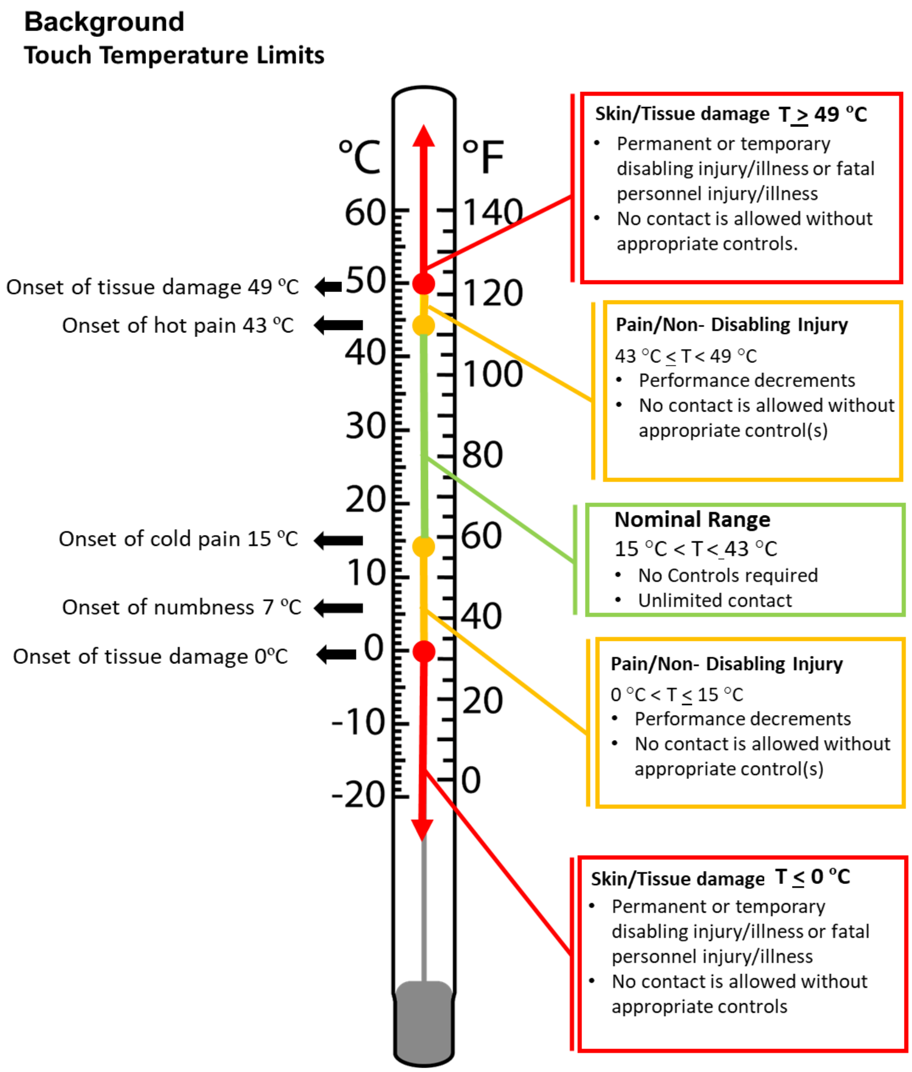


Figure 14—Summary of Bare Skin Exposure Standards Temperature Ranges

Table 20—Summary Table of Bare Skin Exposure Standards Temperature Ranges/Limits

Nominal Thresholds No Controls Required. Unlimited Contact	**Sensation/Pain** (Pain/Non-Disabling Injury/Possibly Resulting in Illness) [V2 9103]	**Skin/Tissue Damage** Controls required [V2 9102]
15°C < T_{skin} < 43°C	**43°C ≤ T_{skin} < 49°C or 0°C < T_{skin} ≤ 15°C**	**T_{skin} ≥ 49°C or T_{skin} ≤ 0°C**

9.3.2.1 Skin/Tissue Damage Temperature Limits

[V2 9102] Any surface to which the bare skin of the crew is exposed **shall not** cause skin temperature to exceed the injury limits in Table 21, Skin Temperature Injury Limits.

[Rationale: Skin Temperature Injury Limits are defined as any condition that may cause a permanent or temporary disabling injury/illness or fatal personnel injury/illness. For touch temperature, this condition was considered when tissue damage may be experienced.
The following references were utilized to determine the limits: Hot: Greene, L.C., et al. (1958) on human tolerance to heat pain showed that the pain threshold is reached at 43.7ºC (110.7ºF) skin temperature. Lloyd-Smith, D.L., and Mendelssohn, K. (1948) found the pain threshold to be 44.6ºC (112.3ºF). Defrin, et al. (2006), found the pain threshold to be between 43-46ºC (109-115ºF). Damage to porcine skin was determined to be at 49ºC (120.2ºF) (Moritz, et al., 1947). Hand dysfunction and the associated safety risk during occupational practices in the cold increases with decreasing skin temperature. Onset of cold pain has been reported to occur between 23°C (73.4ºF) and 14°C (57.2ºF) during cold contact (Havenith, et al., 1992). A marked deterioration in tactile discrimination occurs at finger skin temperatures <8ºC (46.4ºF) with numbness found in one-third of subjects at 7°C (44.6ºF) (Morton and Provins, 1960). Risk of frostbite occurs at 0 °C (32ºF) (Havenith, et al., 1992.). Time of skin exposure may be used as a control; this will depend on material and contact area and may be calculated using thermal models.]

Table 21—Skin Temperature Injury Limits

Tissue Damage	Temperature Threshold Limit
High Temperature Limit	≥49ºC
Low Temperature Limit	≤0ºC

9.3.2.2 Pain/Non-Disabling Injury Skin Temperature Limits

[V2 9103] Any surface to which the bare skin of the crew is exposed **shall** not cause skin temperature to exceed the injury limits in Table 22, Range/Limits Pain/Non-Disabling Injury/Possibly Resulting in Illness.

[Rationale: Pain/Non-Disabling Injury Skin Temperature Limits are defined as any condition which may cause pain, injury, and performance decrements.
*The following references were utilized to determine the limits: Hot: Greene, L.C., et al. (1958) on human tolerance to heat pain showed that the pain threshold is reached at 43.7ºC (110.7ºF) skin temperature. Lloyd-Smith, D.L., and Mendelssohn, K. (1948) found the pain threshold to be 44.6ºC (112.3ºF). Defrin, et al. (2006), found the pain threshold to be between 43-46ºC (109-115ºF). Damage to porcine skin was determined to be at 49ºC (120.2ºF) (Studies of thermal injury ii. The relative importance of time and surface temperature in the causation of cutaneous burns * A. R. Moritz M.D., and F. C. Henriques, Jr., Ph.D. [From the Department of Legal Medicine, Harvard Medical School, Boston, Mass, 1946]. Cold Temperature Limit Values For Touching Cold Surfaces with the Fingertip [Q. Geng, et al., Ann. Occup. Hyg., Vol. 50, No. 8, pp. 851–862, 2006]). Hand dysfunction and the associated safety risk during occupational practices in the cold increases with decreasing skin temperature. Onset of cold pain has been reported to occur between 23°C (73.4ºF) and 14°C (57.2ºF) during cold contact (Havenith, et al., 1992). A marked deterioration in tactile discrimination occurs at finger skin temperatures <8ºC (46.4ºF) with numbness found in one-third of subjects at 7°C (44.6ºF) (Morton and Provins, 1960). Risk of frostbite occurs at 0°C (32ºF) (Havenith, et al., 1992].*

Table 22—Range/Limits Pain/Non-Disabling Injury/Possibly Resulting in Illness

Pain/Performance Decrements	Temperature Threshold Limit
High Temperature Range	43°C $\leq T_{skin} <$ 49°C
Low Temperature Range	0°C $< T_{skin} \leq$ 15°C

The following information is provided to aid designers in determining the duration of contact allowed for different materials before the skin exceeds the temperature limits.

The following tables and figures provide data and outline the methodology for determining the duration of contact time with an object, with respect to the skin temperature limits. In order to calculate the material thermal inertia, use documented thermophysical property resources. Table 23, Inverse Thermal Inertia for Commonly Used Materials, provides Inverse thermal Inertia for Commonly Used Materials. For high (43°C, 49°C) or low (0°C, 15°C) temperatures, use the subsequent figures (15-18) and tables (22-25) to determine the permissible material temperature (T_{PM}) for the expected time of contact.

Table 23—Inverse Thermal Inertia for Commonly Used Materials

Material	Inverse Thermal Inertia $a/\sqrt{(k\ \rho\ c)}$ ($m^2\ s^{0.5}$ K/J)*
Aluminum 6061 T-6	**5.24×10^{-5}**
316 Stainless Steel	**1.420×10^{-4}**
Glass	**6.61×10^{-4}**
Teflon(R)	**1.430×10^{-3}**
Nylon Hook Velcro	**1.400×10^{-2}**

the unit of measure for thermal inertia is ($m^2\ s^{0.5}$ K/J)

Determining Material Temperature and Duration of Contact for 49°C

To determine the maximum permissible material temperature (T_{PM}) and the allowable time of contact to ensure the skin temperature does not exceed the limits:

Use either the equation and constants from Table 24, High Temperature Constants: 49°C, and perform the appropriate calculations;

or

Utilize the calculated and graphed values in Figure 15, High T_{PM} for Incidental and Intentional (Planned) Contact for 49°C.

Table 24—High Temperature Constants: 49°C

$T_{obj} = a/\sqrt{(k\ \rho\ c)}+b$

time (s)	a	b
1	23,600	68.2
10	24,400	54.3
30	24,400	51.9
60	24,400	51.0
¥	24,400	49.6

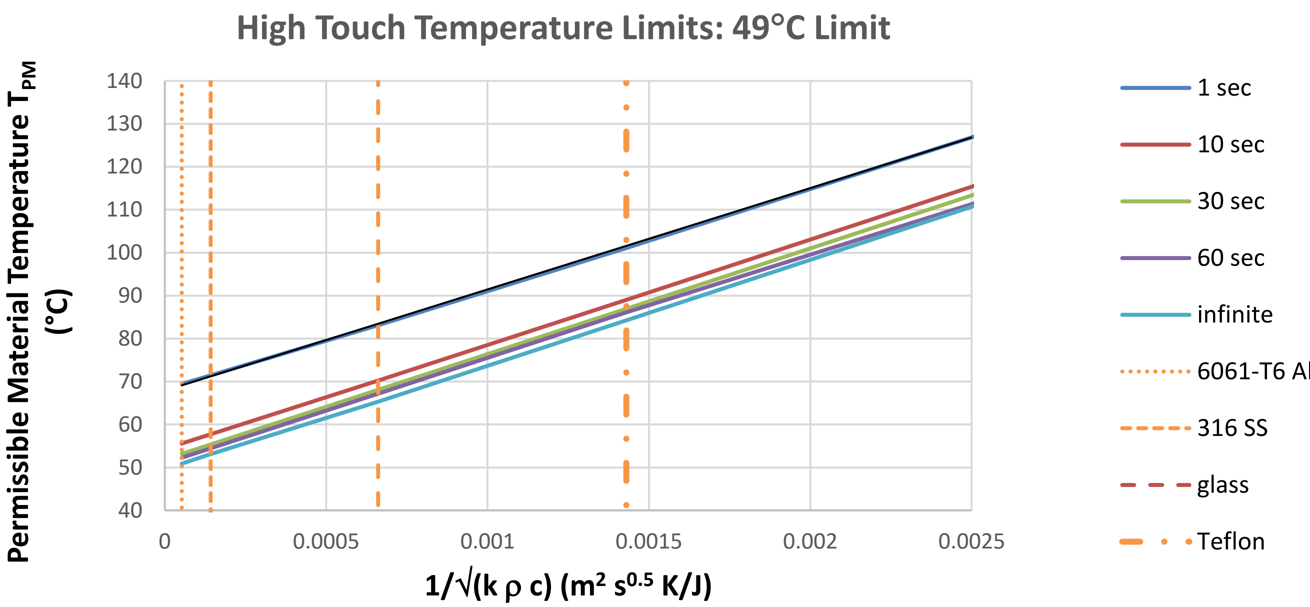


Figure 15—High Temperature T_{PM} for Incidental and Intentional (Planned) Contact (49°C)

Determining Material Temperature and Duration of Contact for 43°C

To determine the maximum permissible material temperature (T_{PM}) and the allowable time of contact to ensure the skin temperature does not exceed the limits:

Use either the equation and constants from Table 25, High Temperature Constants: 43°C, and perform the appropriate calculations;

or

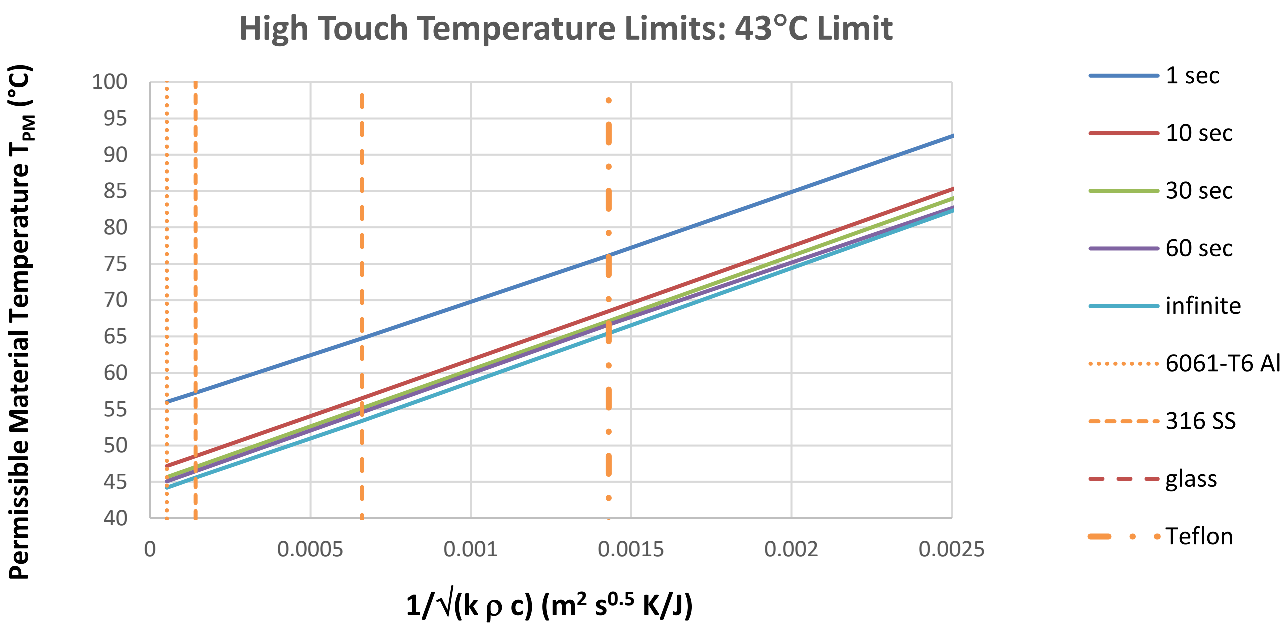
Utilize the calculated and graphed values in Figure 16, High T_{PM} for Incidental and Intentional (Planned) Contact for 43°C.

Table 25—High Temperature Constants: 43°C

$T_{obj} = a/\sqrt{(k\ \rho\ c)}+b$

time (s)	a	b
1	15,500	55.2
10	15,500	46.4
30	15,500	44.8
60	15,500	44.3
¥	15,500	43.4

Figure 16—High T_{PM} for Incidental and Intentional (Planned) Contact (43°C)



Determining Material Temperature and Duration of Contact for 15°C

To determine the maximum permissible material temperature (T_{PM}) and the allowable time of contact to ensure the skin temperature does not exceed the limits:

Use either the equation and constants from Table 26, Low Temperature Constants: 15°C, and perform the appropriate calculations;

or

Utilize the calculated and graphed values in Figure 17, Low T_{PM} for Incidental and Intentional (Planned) Contact for 15°C.

Table 26—Low Temperature Constants: 15°C

$T_{obj} = a/\sqrt{(k\ \rho\ c)}+b$

time (s)	a	b
1s for $a/\sqrt{(k\ \rho\ c)} < 2.34X10^{-4}$	-48,600	0
1s for $a/\sqrt{(k\ \rho\ c)} \geq 2.34X10^{-4}$	-23,800	-5.8
10	-22,700	15
30	-16,600	15
∞	0	15

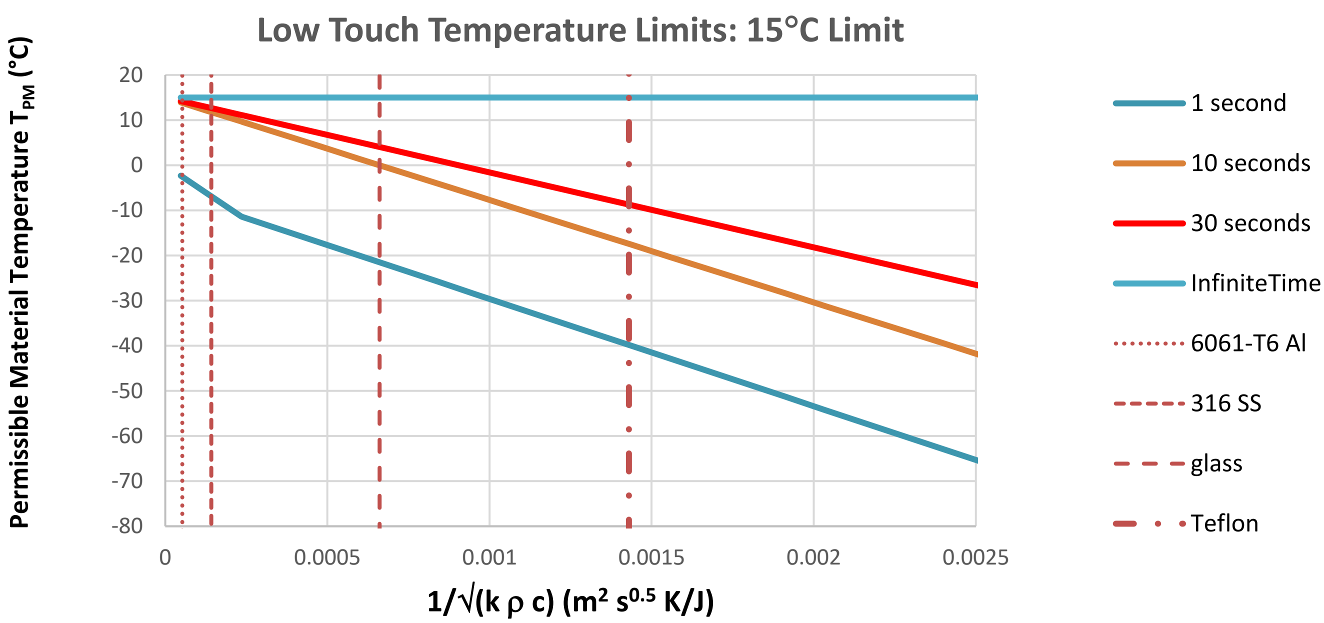


Figure 17—Low T_{PM} for Incidental and Intentional (Planned) Contact (15°C)

Determining Material Temperature and Duration of Contact for 0°C

To determine the maximum permissible material temperature (T_{PM}) and the allowable time of contact to ensure the skin temperature does not exceed the limits:

Use either the equation and constants from Table 27, Low Temperature Constants: 0°C, and perform the appropriate calculations;

or

Utilize the calculated and graphed values in Figure 18, Low T_{PM} for Incidental and Intentional (Planned) Contact for 0°C.

Table 27—Low Temperature Constants: 0°C

$T_{obj} = a/\sqrt{(k\ \rho\ c)}+b$

time (s)	a	b
1	-48,600	0
∞	-19,400	0

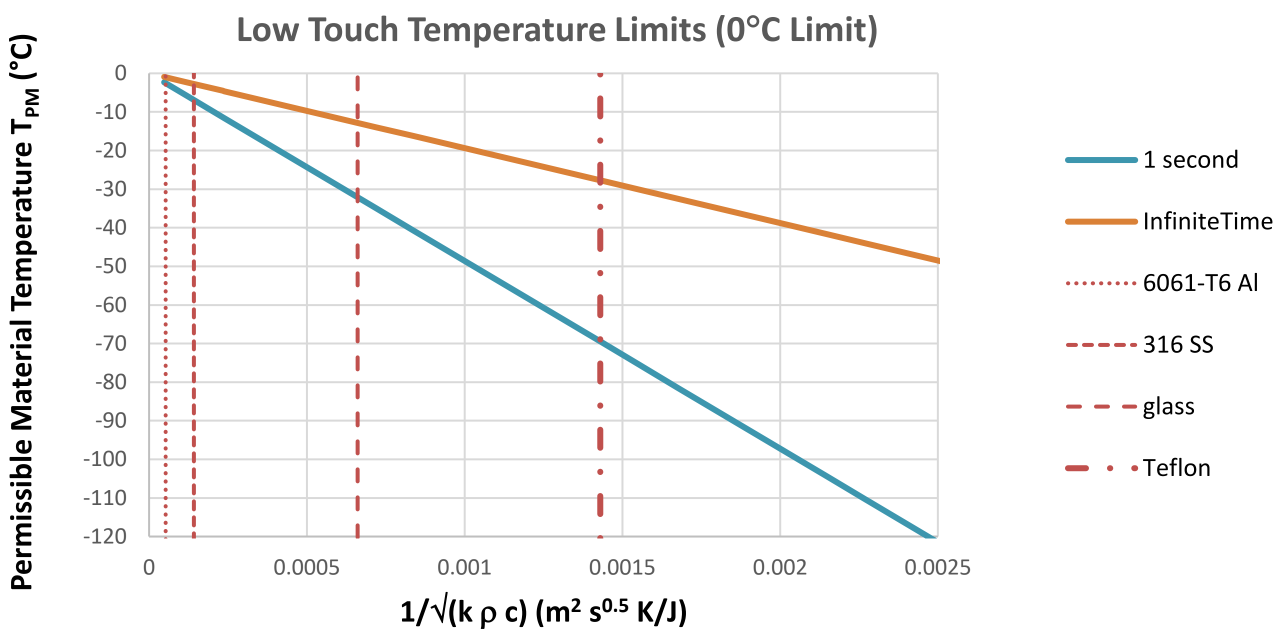


Figure 18—Low TPM for Incidental and Intentional (Planned) Contact (0°C)

9.3.3 Electrical Shock Hazard Minimization

9.3.3.1 Power Interruption

[V2 9017] The system **shall** provide the crew with capability to control the power to an electrical circuit.

[Rationale: This assumes that, at some point in a mission, crew could come in contact with exposed conductors which could cause electrical shock or arcing and/or molten metal resulting in crew injury/death or equipment damage. Thus, there must be a way for the crew to eliminate this exposure by interrupting power, as opposed to only remote control.]

9.3.3.2 Energized Status

[V2 9018] The system **shall** provide and display the de-energized status (interruption of electrical power) of a circuit to the crew and within their fields of regard.

[Rationale: When de-energizing a system, the user should always be provided with feedback that confirms the function has occurred. For efficiency, the display should be visible to the crew without having to move from their position. Because of the critical nature of this information, the complexity of some circuits, and the possibility of a false indication, many times circuit status is verified using a separate tool such as an electromagnetic sensor.]

9.3.3.3 Nominal Physiological Electrical Current Limits

[V2 9019] Under nominal situations (routine human contacts to conductive housing), the program **shall** limit electrical current through the crewmember to ≤ (less than or equal to) 0.4 mA for Direct Current (DC) and ≤ (less than or equal to) 0.2 mA peak for Alternating Current (AC).

[Rationale: These values are below the physiological effect of sensation for the most sensitive members of the astronaut population. This requirement is intended to address typical exposure situations where human contact can routinely occur with conductive housing of electrical equipment, and in these situations no perceptible current flow is the design requirement. Typically, NASA engineering teams establish 1 MΩ (Megaohm) isolation along with grounding to conductive surfaces with Class H or better bond to prevent current flow through crewmembers.]

9.3.3.4 Catastrophic Physiological Electrical Current Limits

The following two requirements set the physiological electrical current limits used in hazard analysis (for all circumstances, [V2 9020] Catastrophic Physiological Electrical Current Limits for all Circumstances, and specifically for unique circumstances where startle reaction may cause a catastrophic event, [V2 9021] Catastrophic Physiological Electrical Current Limits for Startle Reaction), for determining hazard severity, failure tolerance, and controls of a system that could pose a catastrophic electrical shock to the human. These thresholds are used when a hazard analysis is considering failure scenarios and off nominal events where failures such as electrical short circuits have compromised system isolation and pose a risk of catastrophic electrical shock to the human.

9.3.3.4.1 Catastrophic Physiological Electrical Current Limits for all Circumstances

[V2 9020] The program **shall** limit the electrical current through the crewmember to ≤ (less than or equal to) 40mA for DC and ≤ (less than or equal to) 8 mA peak for AC to avoid catastrophic physiological effects to the crewmember.

[Rationale: International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes international standards for all electrical, electronic, and related technologies. The limits for current that could pass through a crewmember were chosen based on the threshold for maintaining muscle control if shocked to protect 99.5% of the population (IEC 60479-2, Effect of current on human beings and livestock, Part 2: Special aspects, Figure 7). This NASA Technical Standard is intended to provide the threshold where additional engineering controls will be required to mitigate the catastrophic nature of electrical shock/physiological effects to the human.

For the above current limits, utilizing the worst-case body impedance of 850 Ω (Ohms) the maximum DC voltage would be 34 volts and the maximum AC voltage would be 6.8 volts. The 850 Ω (Ohms) represents the 5th percentile of the population for a touch voltage of 125 volts and a large contact area (such as full hand or a surface area of 82 cm2) in saltwater-wet conditions (IEC 60479-1, Effects of current on human beings and livestock, Part 1: General Aspects, Table 3). Higher body impedances, and thereby higher voltages, may be allowed based on a case-by-case analysis (contact area, wet conditions etc.) utilizing 5% body impedances tables in IEC 60479-1, and with the approval by the appropriate Safety Panel.]

Note: AC limit is for 50/60 Hz. If different frequencies are required, refer to IEC 60479-2, Figure 2. For different waveshapes and AC/DC combinations, refer to IEC 60479-2 limits. For voltage spikes of short duration (<1 second), refer to IEC TR 60479-5, Effects of current on human beings and livestock, Part 5: Touch voltage threshold values for physiological effects, for limits (Figure 5, curve c1 for AC and Figure 14, curve c1 for DC).

9.3.3.4.2 Catastrophic Physiological Electrical Current Limits for Startle Reaction

[V2 9021] During critical operations where a startle reaction is possible, the program **shall** limit electrical current through the crewmember to ≤ (less than or equal to) 2 mA for DC and ≤ (less than or equal to) 0.5 mA for AC to avoid potentially catastrophic conditions.

[Rationale: IEC is the leading global organization that prepares and publishes international standards for all electrical, electronic, and related technologies. The current values were chosen based on the threshold for a startle reaction if shocked (IEC TR 60479-5, Effects of current on human beings and livestock, Part 5: Touch voltage threshold values for physiological effects, Table 1). Under certain circumstances such as startle reaction, more restrictive thresholds than the physiological catastrophic limits ([V2 9020] Catastrophic Physiological Electrical Current Limits for all Circumstances) may be employed in hazard and risk assessments. Consider the terrestrial examples of involuntary reaction and let go thresholds.

For a person at rest in a chair not performing a critical task, these exposures are not catastrophic. However, consider an electrician on a ladder or the pilot of an aircraft where split second involuntary reactions can have dire consequences where the threshold of safety should be set lower at the startle reaction electrical current values. The application of these lower thresholds would be case-by-case in unique circumstances where it is deemed appropriate, such as during manual control of a spacecraft or during EVA. For the above current limits, utilizing *the worst-case body impedance of 850 Ω (Ohms), the maximum DC voltage would be 1.7 volts and the maximum AC voltage would be 0.4 volts. The 850 Ω (Ohms) represents the 5th percentile of the population for a touch voltage of 125 volts and a large contact area (such as full hand or a surface area of 82 cm2) in saltwater-wet conditions (IEC 60479-1, Effects of current on human beings and livestock, Part 1: General Aspects, Table 3). Higher body impedances, and, thereby, higher voltages, may be allowed based on a case-by-case analysis (contact area, wet conditions, etc.) utilizing 5% body impedances tables in IEC 60479-1 and with the approval by the appropriate Safety Panel.]*

Note: AC voltage is for 50/60 Hz. If different frequencies are required, refer to IEC 60479-2, Effect of current on human beings and livestock, Part 2: Special aspects, Figure 2. For different wave shapes and AC/DC combinations, refer to IEC 60479-2 limits.

9.3.3.5 Body Impedance for Voltage Calculations Utilizing Electrical Current Thresholds

[V2 9022] The program/project **shall** use the 5^{th} percentile values for the appropriate conditions (wet/dry, AC/DC, voltage level, large/small contact area) from IEC 60479-1, Effects of current on human beings and livestock - Part 1: General Aspects, to determine the appropriate body impedance to calculate the voltage associated with any current limit analysis.

[Rationale: IEC is the leading global organization that prepares and publishes international standards for all electrical, electronic, and related technologies. For example, 850 Ω (Ohm) represents the 5^{th} percentile of the population for a touch voltage of 125 volts and a large contact area (such as full hand or a surface area of 82 cm^2) in saltwater-wet conditions (IEC 60479-1, Table 3). Higher body impedances and, thereby, higher voltages, may be allowed based on a case-by-case analysis utilizing 5% body impedances tables with the approval of the program's Safety Panel. Higher body impedances and, thereby, higher voltages, may be allowed based on a case-by-case analysis utilizing 5% body impedances tables with the approval of the program's Safety Panel.]

9.3.3.6 Leakage Currents – Equipment Designed for Human Contact

[V2 9023] For equipment such as bioinstrumentation and medical devices, that are specifically designed to contact the human body, electrical leakage currents caused by contact with exposed surfaces **shall** be kept below the levels specified in Table 28, Leakage Currents-Medical and Bioinstrumentation Equipment.

[Rationale: Some equipment needs to pass small amounts of current through the body to accomplish its intended function, e.g., bias currents in medical monitoring equipment. The amount of current allowed depends on the frequency and whether the part of the equipment contacting the crewmember is isolated from the power source. Examples of isolated equipment are intra-aortic catheters and electrocardiogram (ECG) monitors. Examples of non-isolated equipment are blood pressure cuffs and digital thermometers. These levels of leakage current are consistent with those in IEC 60601-1, Medical Electrical Equipment – Part 1: General

Requirements for Basic Safety and Essential Performance, for patient auxiliary and patient leakage currents in isolated (type CF) and non-isolated (types B and BF) equipment. These leakage currents are measured across parts applied to the crewmember and from the applied parts to ground. The summation of all the currents should be compared to the current limits in Table 28.]

Table 28—Leakage Currents – Medical and Bioinstrumentation Equipment

<table>
<tr><th colspan="5">Maximum Current (mA)</th></tr>
<tr><th rowspan="2">Body Contact</th><th rowspan="2">Frequency</th><th rowspan="2">Operating Condition</th><th colspan="2">Equipment Type</th></tr>
<tr><th>Isolated Equipment</th><th>Non-Isolated Equipment</th></tr>
<tr><td rowspan="4">External*</td><td rowspan="2">DC to 1 kHz</td><td>Normal</td><td colspan="2">0.1</td></tr>
<tr><td>Single Fault</td><td colspan="2">0.5</td></tr>
<tr><td rowspan="2">>1 kHz</td><td>Normal</td><td colspan="2">f (kHz) x 0.1 (must be ≤ 5)</td></tr>
<tr><td>Single Fault</td><td colspan="2">f (kHz) x 0.5 (must be ≤ 5)</td></tr>
<tr><td rowspan="4">Internal</td><td rowspan="2">DC to 1 kHz</td><td>Normal</td><td>0.01</td><td rowspan="4">Not Allowed</td></tr>
<tr><td>Single Fault</td><td>0.05</td></tr>
<tr><td rowspan="2">>1 kHz</td><td>Normal</td><td>f (kHz) x 0.01 (must be ≤ 1)</td></tr>
<tr><td>Single Fault</td><td>f (kHz) x 0.05 (must be ≤ 1)</td></tr>
<tr><td colspan="5">*For DC, there is a small risk of heating and tissue necrosis for prolonged duration of contact.</td></tr>
</table>

9.3.4 Fluid and Gas Spill Hazard Minimization

9.3.4.1 Fluid/Gas Release

[V2 9024] Hardware and equipment **shall** not release stored fluids or gases in a manner that causes injury to the crew.

[Rationale: Crew injuries are likely to be caused by either highly pressurized fluids and gases or toxic fluids and gases. In both cases, design requirements are to be developed so that the crew is protected during both storage and handling of these fluids and gases.]

9.3.4.2 Fluid/Gas Isolation

[V2 9025] The system **shall** provide for the isolation or shutoff of fluids in hardware and equipment.

[Rationale: Fluids are most likely to be temporarily shut off at service and maintenance points. System developers are to identify those points and create isolation capabilities. Without dedicated isolation controls, crews could create bypasses, which waste crew time and possibly damage systems. Also, to save time and reduce the possibilities of error, e.g., forgetting to shut them off or to turn them back on when maintenance is complete, the shut-off valves are to be located near those service points and operable while wearing the most encumbering equipment and clothing anticipated.

Note: The term fluid includes both liquid as well as gas.]

9.3.4.3 Fluid/Gas Containment

[V2 9026] The system **shall** provide for containment and disposal of fluids that might be released during operation or maintenance.

[Rationale: Excess fluids are likely to be released during draining and filling of systems. Designs are to accommodate these possibilities to ensure free fluid control, collection, containment, or disposal that is safe and effective. Some examples of control, collection, and disposal methods include fluid-sealed connectors, volume sensors, flow sensors, overflow valves, accumulators, vacuum systems, and system waste venting. Collection and containment facilities are to be located near the points where release is likely to occur (maintenance or service points). Control of unexpected gas and fluid release due to system or component failure are to be assessed by safety hazard analysis. This requirement applies to fluids under the system's control.]

9.4 Durability

9.4.1 Protection

[V2 9027] Systems, hardware, and equipment **shall** be protected from and be capable of withstanding forces imposed intentionally or unintentionally by the crew.

[Rationale: Unintentional damage can occur if items are in a location where crew is focused on other activities such as translation, moving equipment, or maintaining other systems. Designers are to identify areas of crew activity and decide if exposed hardware and equipment are sufficiently durable for unintended forces. Such hardware and equipment may have to be relocated, guarded, covered, e.g., with close-out panels, or simply designed to be more durable. "Intentional" damage may result from crewmembers securing or tightening items (latches, retainers, bolts, screws, etc.) using forces beyond their design limits. This often occurs under panic conditions. Hardware designers are to use crew strength data and to assume the crew could apply their maximum strength forces.]

9.4.2 Isolation of Crew from Spacecraft Equipment

[V2 9028] Protective provisions, e.g., close-out panels, **shall** be provided to isolate and separate equipment from the crew within the habitable volume.

[Rationale: Protective provisions such as closeout panels serve the following functions: provide protection from forces in accordance with [V2 9027] Protection, in this NASA Technical Standard; provide fire abatement protection and isolation and support of fire extinguishing operations; protect crew from ignition sources and sharp edges and retain debris from coming out into habitable volume; protect equipment from ground or flight crew operations; provide acoustic barrier for noise generated behind panels; minimize snag potential; and prevent loose items or equipment from becoming lost. In addition, protective provisions are designed to

provide a smooth surface, faired-in with the adjacent crew compartment structure, and be compatible with crew passageway requirements.]

9.5 Assembly and Disassembly

9.5.1 Hardware and Equipment Mounting and Installation

[V2 9029] System hardware and equipment **shall** be designed so that it cannot be mounted or installed improperly.

[Rationale: Ideally, similar items are interchangeable. The preferred method of preventing improper installation and mating is a design that prevents it such as misaligned mounting holes, pins, or keys. The designs to prevent installation and mating errors are to be rugged enough to withstand persistent attempts. Cues (such as color or labeling) can be provided to remind crewmembers, so they save the time of trying to make improper installations. However, these cues are not to be the sole countermeasure to improper installation and mating.]

9.5.2 Mating and Demating

9.5.2.1 Connector Spacing

[V2 9030] The spacing between connectors **shall** permit mating and demating by crewmembers wearing expected clothing.

[Rationale: Adequate access and working space allows personnel to efficiently access equipment in a way that allows nominal and off-nominal tasks to be performed. Access to connectors may be required during equipment assembly, reconfiguration, or maintenance. Access and work envelopes are different for differing tasks. In particular, protective garments, e.g., spacesuits, may be required by the flight crew and are to be accommodated.]

9.5.2.2 Connector Actuation without Tools

[V2 9031] Connectors **shall** be operable without tools for mating and demating while wearing the most encumbering equipment and clothing anticipated.

[Rationale: Connector actuation includes mating/connecting and demating/disconnecting of a connection. Lost or damaged tools prevent connectors from being connected or disconnected, which may result in LOC or LOM.]

9.5.2.3 Incorrect Mating, Demating Prevention

[V2 9032] Cable, gas and fluid lines, and electrical umbilical connectors **shall** prevent potential mismating and damage associated with mating or demating tasks.

[Rationale: Ideally, similar items are interchangeable. The preferred method of preventing improper installation and mating is a design that prevents it such as misaligned mounting holes, pins, or keys. The designs to prevent installation and mating errors are to be rugged enough to withstand persistent attempts. Cues (such as color or labeling) can be provided to remind crewmembers, so they save the time of trying to make improper installations. However, these cues are not to be the sole countermeasure to improper installation and mating.]

9.5.2.4 Mating, Demating Hazards

[V2 9033] The system **shall not** subject personnel and equipment to hazards, including spills, electrical shocks, and the release of stored energy, during mating or demating.

[Rationale: Maintenance or service tasks are not likely to be familiar, and thus crews may be more focused on these tasks. Hazards that would normally be identified and avoided may go unnoticed during maintenance. Design requirements and solutions are to identify hazards that are exposed during maintenance activities and determine ways to eliminate these hazards or protect the crew from them.]

9.6 Cable Identification and Management

9.6.1 Cable Management

[V2 9034] The system **shall** manage cable, wire, and hose location, protection, routing, and retention to prevent physical interference with crew operations and safety.

[Rationale: Designers are to define areas of activity and route fixed lines and cables so that they are both protected and also do not interfere with these activities. Pressurized lines and hoses should be restrained to prevent crew injury. Also, system designers are to focus on non-fixed lines and cables that may be unstowed or moved for a specific task or temporary rearrangement. While the rerouted cable or line may accommodate a specific need, the routing path may interfere with other, non-related activities such as crew translation and egress. Designers are to identify potential uses for lines and cables and ensure the start points, end points, and cable and line routes in between accommodate all crew activities.]

9.6.2 Cable Identification

[V2 9035] All maintainable cables, wires, and hoses **shall** be uniquely identified.

[Rationale: Some conductors do not terminate in a keyed connector; they are individually attached. It is essential that the conductors be attached to the correct terminal points. All individual conductors that attach to different terminal points are to be coded. Terminal points are normally fixed and can be identified with labels and illustrations. Conductors, on the other hand, are to have identifications affixed to them. This is normally done with color coding of the insulation materials or by tagging the conductors.]

9.7 Design for Maintainability

Maintenance constitutes a large portion of a system lifecycle and it can consume a significant amount of time during a mission. Designing for maintainability involves system level optimization for parts, analyzing the resulting ergonomics, and considering tools and information as part of the design.

9.7.1 General

9.7.1.1 Design for Maintenance

[V2 9036] The system **shall** provide the means necessary for the crew to safely and efficiently perform routine service, maintenance, and anticipated unscheduled maintenance activities while wearing the most encumbering equipment and clothing anticipated.

[Rationale: Maintenance and servicing are not directly related to mission goals. Reduction in the time devoted to maintenance and servicing can mean more crew time devoted to achieving mission goals. Also, because of the complexity of space missions and the interdependency of many factors (equipment, supplies, weather, solar flares, political considerations, etc.), designs are to minimize reliance on outside maintenance support. Designs are to provide the tools, parts, supplies, training, and documentation necessary for crews to maintain efficient and safe operations.]

9.7.1.2 Commercial Off-the-Shelf (COTS) Equipment Maintenance

[V2 9037] Maintenance for commercial off-the-shelf equipment **shall** be suitable to the space flight environment.

[Rationale: Systems designed for terrestrial environments may be adapted for space missions. This adaptation is to include procedures and features that will allow maintenance tasks to be performed safely and effectively in a space mission environment. Major changes that likely need accommodation are differences in gravity or crewmembers wearing gloves.]

9.7.1.3 In-Flight Tool Set

[V2 9038] Each program **shall** establish a set of in-flight tools necessary to maintain or reconfigure the space flight system. Also, tools are to be usable by the full range of crew sizes and strengths wearing any protective equipment (EVA suits, protective eyewear, gloves, etc.).

[Rationale: Tool set design is to be based partly on reducing the demands on the crew: selecting tools that are likely to be familiar to crewmembers and minimizing the number of different tools.]

9.7.2 Maintenance Efficiency

9.7.2.1 Maintenance Time

[V2 9039] Planned maintenance for systems and associated hardware and equipment **shall** be capable of being performed within the allotted crew schedule while wearing the most encumbering equipment and clothing anticipated.

[Rationale: Maintenance and servicing are directly related to the amount of time available for mission goals. Reduction in the time devoted to maintenance and servicing means more crew time devoted to achieving mission goals. Also, because of the complexity of space missions and the interdependency of many factors (equipment, supplies, weather, solar flares, political considerations, etc.), designs are to minimize reliance on outside maintenance support. Designs are to provide the tools, parts (as modular units where possible), supplies, training, and documentation necessary for crews to maintain efficient and safe operations.]

Deleted:

[V2 9040] Requirement deleted.

Deleted:

[V2 9041] Requirement merged into [V2 9039].

9.7.2.2 Captive Fasteners

[V2 9042] Fasteners used by the crew during maintenance **shall** be captive.

[Rationale: Freed fasteners become Foreign Object Debris (FOD) in microgravity, which pose a risk during the mission. Fasteners can be lost either by loosening during normal use or by becoming misplaced during maintenance operations. Space missions are generally isolated, and replacement parts are not available. This is particularly important in zero gravity environments because small items such as fasteners can be very difficult to find.]

9.7.2.3 Minimum Number of Fasteners - Item

[V2 9043] For items that may be serviceable by the crew, the number of fasteners used **shall** be the minimum required to meet structural engineering design practices.

[Rationale: Designers can add a safety factor to some configurations by increasing the number of fasteners. However, when crews are to routinely remove the fasteners, selection of the number of fasteners is also to consider reduction of crew time devoted to maintenance activities.]

9.7.2.4 Minimum Variety of Fasteners - System

[V2 9044] The system **shall** be serviceable with a common set of fasteners that meet structural engineering design practices.

[Rationale: Different fasteners require different tools and procedures for removal and replacement. Commonality of fasteners can reduce times to access and the need for different tools. It can also reduce training times necessary to introduce crews to the fastener types.]

9.7.3 Accessibility

9.7.3.1 Maintenance Item Location

[V2 9045] The system **shall** locate maintenance items so that the maintenance task does not require the removal or disabling of other systems or components.

[Rationale: Location of items depends on many factors (physical room, interface with other items, manufacturing considerations, etc.), and maintenance can be easily overlooked. It is important, therefore, that, early in a design, system developers identify those items that will require maintenance. Accessibility to those items then becomes a higher priority in selecting the location of these items.]

9.7.3.2 Check and Service Point Accessibility

[V2 9046] Check points and service points for systems, hardware, and equipment **shall** be directly accessible while wearing the most encumbering equipment and clothing anticipated.

[Rationale: System designs are to support mission goals that do not normally devote crew time to maintenance tasks. Removal of items to access check and service points increases maintenance times. Also, complex and time-intensive maintenance procedures could discourage performance of scheduled tasks.]

9.7.3.3 Maintenance Accommodation

[V2 9047] Physical work access envelopes **shall** accommodate the crew, required tools, and any protective equipment needed to perform maintenance.

[Rationale: Maintenance tasks are to be defined and analyzed with worst-case assumptions. Volume is to be provided to allow the size extremes in the crewmembers performing the tasks using proper tools and protective equipment within the prescribed times. Hand clearance for in-flight maintenance tasks is to be provided by the hardware developer to ensure that maintenance tasks can be performed while wearing the most encumbering equipment and clothing anticipated.]

9.7.3.4 Visual Access for Maintenance

[V2 9048] Maintenance tasks that require visual feedback **shall** be directly visible during task performance while wearing the most encumbering equipment and clothing anticipated.

[Rationale: Efficient and safe performance of many maintenance tasks requires vision during task performance. In crowded spaces, hands and tools can block vision of the task. On those tasks that require vision during task performance (such as alignments or adjustments), designers are to locate and design equipment to provide this vision.]

Deleted:

[V2 9049] Requirement merged into [V2 9047].

9.7.3.5 Tool Clearance

[V2 9050] The system **shall** provide tool clearances for tool installation and actuation for all tool interfaces during in-flight maintenance.

[Rationale: Tools to be used for in-flight maintenance are to be identified by the hardware developer, and clearance for application is to be accommodated to ensure that maintenance tasks can be performed.]

9.7.4 Failure Notification

9.7.4.1 Fault Detection

[V2 9051] The system **shall** provide rapid and positive fault detection and isolation of defective items.

[Rationale: Fault detection is a means to reduce crew time devoted to maintenance activities. Properly designed aids to fault detection and isolation can also reduce crew training requirements. Terminology, references, and graphics used are to be coordinated with other crew task demands to minimize additional training. Designers are to define systems that are likely to fail and then create features that help identify these failures when they occur. In addition to the fault detection and isolation capabilities, the crew is to be provided tools and supplies to maintain and repair the defective systems.]

9.7.4.2 Failure Notification

[V2 9052] The system **shall** alert the crew when critical equipment has failed or is not operating within tolerance limits.

[Rationale: An alerting system allows crew to quickly surmise a system or component failure. Terminology, references, and graphics used are to be coordinated with other crew task demands to minimize additional training.]

9.8 Protective and Emergency Equipment

9.8.1 Protective Equipment

9.8.1.1 General

9.8.1.1.1 Protective Equipment

[V2 9053] Protective equipment **shall** be provided to protect the crew from expected hazards.

[Rationale: Protective equipment is not used as a control to protect crew from expected hazards in that design hazard controls, failure tolerance, design for minimum risk are necessary to protect the crew from "expected" hazards. Analyses are to define anticipated hazards and appropriate protective equipment. Protective equipment might include gloves, respirators, goggles, and pressure suits (as specified in [V2 11100] Pressure Suits for Protection from Cabin Depressurization. The equipment is to fit the full range of crewmembers. This might require adjustable gear or multiple sizes (with consideration of the number of crewmembers that may have to use the equipment at the same time). Because the gear could be used under emergency conditions, it is to be located so that it is easily accessed and is to be simple to adjust and don.]

9.8.1.1.2 Protective Equipment Use

[V2 9054] Protective equipment **shall not** interfere with the crew's ability to conduct the nominal or contingency operations that the crew is expected to perform while employing the protective equipment, including communication among crewmembers and with ground personnel.

[Rationale: Analyses are to be performed of the situations and operations in which protective equipment is to be used. This analysis is to define the task demands and the requirements for protective equipment design. Task performance demands might include visibility, range of motion, dexterity, and ability to communicate.]

9.8.1.1.3 Protective Equipment Automation

[V2 9055] Automation of protective equipment **shall** be provided when the crew cannot perform assigned tasks.

[Rationale: The crew may need to perform tasks to activate protective equipment operation or to activate rescue aids. If these tasks are to be performed under emergency or stressful conditions (where the crewmember is distracted or disabled), then the tasks are to be automated. An example of an automatically activated protective system is the automatic parachute release

device. The emergency locator transmitter in an airplane is an example of an automatically activated rescue system.]

9.8.1.2 Hearing Protection

9.8.1.2.1 Use of Hearing Protection

[V2 9056] The system **shall** meet SPL limits of section 6.6.1, Acoustic Limits, in this NASA Technical Standard, except where otherwise specified in this NASA Technical Standard, without requiring the use of personal hearing protection.

[Rationale: Hearing protection normally operates by decreasing the level of sound at the ear (passive protection). Normal, long-term operations are to be conducted without the impairment to hearing from hearing protection. This would interfere with the ability to communicate and hear audio signals. In some situations (such as launch and reentry), however, noise levels may be uncontrollably high for relatively short periods. Facilities for communications and audio signals can be adapted so that they are possible in those situations. Requirements are to specify those periods allowing the use of hearing protection, and then designs are to accommodate effective crew functioning during that time.]

9.8.1.2.2 Hearing Protection Provision

[V2 9057] Appropriate personal hearing protection **shall** be provided to the crew during all mission phases for contingency or personal preference.

[Rationale: Crewmembers are to have readily accessible hearing protection for unanticipated high noise levels. Hearing protection is also to be available to block noise according to individual preferences such as for concentration or for sleep.]

9.8.1.2.3 Hearing Protection Interference

[V2 9058] The system **shall** be designed so that hearing protection does not inhibit voice communication, monitoring of systems, and detection of alerts.

[Rationale: Some conditions might temporarily expose the crew to high noise levels. Facilities for communications and audio signals can be adapted so that they are possible in those situations. Requirements are to specify those periods allowing the use of hearing protection, and then designs are to accommodate effective crew functioning during that time.]

9.8.2 Fire Protection System

9.8.2.1 Fire Detecting, Warning, and Extinguishing

[V2 9059] A fire protection system comprised of detecting, warning, and extinguishing devices **shall** be provided to all spacecraft volumes during all mission phases without creating a hazardous environment.

[Rationale: Fire protection is to be based on the anticipated nature of the fire and the likely location of the crew in the event of a fire. Automated systems are to be used where crews are not capable of extinguishing fires (large fires or fires where crew could be absent, or fires in volumes inaccessible to the crew). Other systems may be effectively protected with portable extinguishers. Hand-operated extinguishers are to be clearly labeled and easily accessed by the crew. All extinguishing systems are not to create any additional hazardous conditions for the crew.]

9.8.2.2 Fire Protection System Health and Status

[V2 9060] The fire protection system health and status data **shall** be provided to the crew and other mission systems.

[Rationale: Design requirements are to ensure that the crew has the capability of determining the health and status of the fire protection system. The crew is to be aware as soon as possible when the fire protection system has failed or is unreliable.]

9.8.2.3 Fire Protection System Failure Alerting

[V2 9061] The crew **shall** be alerted to failures of the fire protection system.

[Rationale: Design requirements are to ensure that the crew is notified in the event the fire protection system fails. The crew is to be aware as soon as possible when the fire protection system cannot be relied upon.]

9.8.2.4 Fire Protection System Activation

[V2 9062] The fire protection system **shall** be capable of being manually activated and deactivated.

[Rationale: Automated systems may fail and not respond correctly to a fire or may continue extinguishing after a fire is under control. Design requirements are to ensure that the crew is provided with a fire protection system that allows for manual activation and deactivation.]

9.8.2.5 Portable Fire Extinguishers

[V2 9063] A fire protection system **shall** include manually operated portable fire extinguishers usable while wearing the most encumbering equipment and clothing anticipated.

[Rationale: Small fires might be detected and controlled early (before detection by an automated system). Design requirements are to ensure that the crew is provided with a portable fire-fighting capability, even if a fixed firefighting system is provided.]

9.8.3 Emergency Equipment Accessibility

[V2 9064] Emergency equipment **shall** be clearly identified, accessible, and useable to complete emergency response in the time required during all mission phases where the corresponding emergency may occur while wearing the most encumbering equipment and clothing anticipated.

[Rationale: Design requirements are to consider all emergency scenarios requiring access to emergency equipment. Clear identification of emergency equipment includes markings, placards, labels, or etchings. The location and proximity of emergency equipment, with respect to the crew, impacts the accessibility of emergency equipment. For equipment to be usable, its design has to consider the crew-system interfaces to allow crew to safely, accurately, and completely respond to the emergency (e.g., fire). The design also has to account for the effects of the specific environment where the equipment may be used (e.g., microgravity, partial gravity). Requirements need to be defined in terms of time constraints to perform emergency actions. Furthermore, each emergency may have a unique time requirement and, therefore, a different constraint on access. Refer to HIDH for guidance on emergency response times, including fire extinguishment times.]

10. HUMAN PERFORMANCE AND CREW INTERFACES

The system needs to support safe operations by adequately supporting the crew in both nominal and off-nominal situations, i.e., ensuring that the integrated design remains within acceptable performance envelopes. Indications of adequate crew support include: (1) tasks can be accomplished within planned time and performance criteria, (2) the human-system interface supports a high degree of onboard SA, (3) the system design and allocation of functions provide acceptable workload levels to ensure vigilance and a balance between underload/boredom and overload, and (4) the system design minimizes design-induced error conditions and enables the crew to detect and respond to system errors.

This section covers the crew interfaces through which static and dynamic information is exchanged between the crew and the system (primarily through controls and displays). Well-designed crew interfaces are critical for crew safety and productivity, and for minimizing training requirements. Visual displays deliver information by using visible media to present text, graphics, colors, images, video, animations, and symbols. Audio displays deliver information using sound and include voice communication and audio alarms. Haptic displays deliver information using the sense of touch for the purpose of information presentation. Labels form a *distinct class of crew interfaces, usually providing a static identification of a device or device component, or brief static message. Labels may consist of text or graphic symbols. Communication systems form another special class of crew interfaces involving ongoing dynamic exchange of voice, text, video, and/or telemetry information between humans or between humans and systems.*

10.1 General

10.1.1 Integrated Human Performance

The system needs to adequately support the crew to operate safely in both nominal and off-nominal situations, i.e., that the integrated design remains within acceptable performance envelopes. Indications of adequate crew support include: (1) tasks can be accomplished within time and performance criteria, (2) the human-system interface supports a high degree of onboard SA, (3) the system design and allocation of functions provide acceptable workload levels to ensure vigilance and a balance between underload/boredom and overload, and (4) the interfaces minimize operator error and provide for error detection and recovery when events do occur. Verification of integrated human performance requirements requires HITL testing using appropriate tools and methods.

10.1.1.1 Crew Interface Usability

[V2 10001] The system **shall** provide crew interfaces that result in a NASA-modified System Usability Scale (SUS) score of 85 or higher.

[Rationale: Systems that are usable are acceptable and operable by the intended user for performing expected tasks. If a design does not meet the users' needs, expectations, intuitions, or capabilities, and as a result causes frustration or confusion, the design is not effective. Ineffective design may directly or indirectly impact operational timelines, crew stress and behavioral health, or safety. Errors may occur, tasks may take longer to complete, or users may abandon, work around, or choose not to perform the tasks. Design for perceived crew acceptability is guided by task analysis and iterative prototyping and evaluation. Human-in-the-loop acceptability evaluation is conducted early and throughout system design to gather user feedback on design effectiveness, efficiency, and potential design-induced errors to influence design improvements and measure design progress. While many tools exist for assessing user acceptability, NASA recommends use of the SUS with participants that have been trained on the tasks and system design to a pre-set performance criterion throughout design development. SUS is a reliable instrument that is short and easy to administer and is valuable for eliciting feedback on specific design elements for iterative improvement. The SUS scale and information on scoring and interpreting results can be found at https://measuringu.com/sus.]

10.1.1.2 Design-Induced Error

[V2 10002] The system **shall** provide crew interfaces that result in the maximum observed error rates listed in Table 29, Maximum Observed Design-Induced Error Rates.

[Rationale: Errors are detrimental to crew effectiveness, efficiency, acceptability, and safety. Even when recoverable or resulting in minimal impact, errors can still negatively impact crew performance in terms of productivity and satisfaction. Errors are defined as an action that does not result in the intended outcome or a failure by the crew to perform an action within the required limits of accuracy, sequence, or time which results in unwanted consequences. Design-induced errors include, but are not limited to: missed or incorrect inputs or selections, display navigation errors, errors due to inadequate hardware component design, errors due to lack of system feedback to user inputs, errors due to inadequate information, errors due to design inconsistency or unfamiliar terminology, and the inability to complete a step or task. Unintentional errors that are related to human reliability (e.g., bumping a control due to fatigue) are not considered design-induced errors.

It is crucial for design to be guided by an iterative, human-centered design process including task analysis, human error analysis, and HITL evaluations. Task analyses identify user tasks and task sequences. To ensure crew have situation awareness, detailed analysis of information needs are performed to identify the needed information is presented in the context necessary for crew to perform the correct actions at the correct time. Human error analysis identifies potential user errors at each step and the outcome or system consequence if the error is committed. Task errors that would result in a catastrophic outcome should be prevented through careful interface design and thorough evaluation. Tasks that are identified as complex, leading to critical or catastrophic hazards/events, or frequent need more rigorous developmental testing and are to be included in HITL verification testing.

For purposes of HITL testing, a scenario requiring evaluation will be defined as an activity driven by one or more related and sequential procedures. The procedure consists of a series of task steps, where a task step will be defined as a single instruction to the test subject, as is typical of current space flight procedures. Participants will maintain task completion times commensurate with the performance requirements.

- *If any errors classified as having the potential of leading to a catastrophic outcome occur, the root cause of the error must be identified, mitigated satisfactorily (approved by NASA), and a re-test of the task performed to prove that the error has been eliminated.*
- *The percentage of errors (erroneous task steps) for each user shall be calculated by dividing the number of erroneous task steps and incomplete task steps by the total number of task steps and multiplying the result by 100.*
- *The percentage of users committing each error (erroneous task step) shall be calculated by dividing the number of users committing each erroneous task step by the total number of users and multiplying the result by 100.]*

Table 29—Maximum Observed Design-Induced Error Rates

Type of Error	Maximum Observed Error Rate
Catastrophic Error	0%
Non-Catastrophic Errors per User per Task	5%
Non-Catastrophic Errors per Step per Task	10%

10.1.1.3 Crew Interface Operability

[V2 10003] The system **shall** provide interfaces that enable crewmembers to successfully perform tasks within the appropriate timeframe and degree of accuracy.

[Rationale: Operability is the ability of the intended user to achieve the required or desired outcome, within the planned or required time to effect and degree of accuracy, using the system and procedures as designed. Successful task performance within the appropriate completion time and degree of accuracy is an objective measures of design usability and effectiveness. Ineffective design may directly or indirectly impact operational timelines, crew stress and behavioral health, or safety. Design for operability is guided by function and task analysis, iterative design, and HITL evaluation. To ensure crew have SA, detailed analysis of information needs should be performed to ensure needed information is presented in the time and context necessary for crew to perform correct actions at the correct time. The task analysis will define tasks where timing and degree of accuracy is critical, as well as the performance outcome parameters. The human, along with the hardware/software systems, must be able to complete such tasks within the time constraints. HITL operability evaluation should be conducted early and throughout system design to gather user feedback on design effectiveness, efficiency, and potential design-induced errors to influence design improvements and measure design progress.]

10.1.1.4 Cognitive Workload

[V2 5007] The system **shall** provide crew interfaces that result in Bedford Workload Scale ratings of 3 or less for nominal tasks and 6 or less for off-nominal tasks.

[Rationale: Cognitive workload is the users' perceived level of mental effort that is influenced by many factors, particularly task load and task design. Acceptability of cognitive workload level for critical or frequent operations/task sequences should be measured using a validated workload scale such as the Bedford Workload Scale. On the Bedford scale, acceptable level of workload is a rating of 3 or less for critical or frequent tasks, and 6 or less for infrequent, non-critical tasks. The workload measurement enables standardized assessment of whether temporal, spatial, cognitive, perceptual, and physical aspects of tasks and the crew interfaces for these tasks are designed and implemented to support each other. Application of workload measurement for crew interface and task designs in conjunction with other performance measures, such as usability and design-induced error rates, helps assure safe, successful, and efficient system operations by the crew. Workload levels may be modulated (raised or lowered) through the combination of user-interface design and task design (e.g., task simplification, subtask combination and sequencing, and the distribution of tasks among multiple crewmembers and between crew and automation).]

10.1.1.5 Physical Workload

[V2 10200] The system **shall** provide crew interfaces that result in a Borg-CR10 rating of perceived exertion (RPE) of 4 (somewhat strong) or less.

[Rationale: The design of interfaces for physical tasks is important because of the risks of musculoskeletal injuries and disorders that arise out of mismatch between a crew capability and the physical demands of their task. Minimizing these risks is especially important for space flight where schedule and specialized crew training for unique tasks and environments cannot easily be adjusted. Attention should be paid to design of tasks that are high effort, extended duration, or involve repetitive motions that can result in over-exertion or fatigue, such as suit donning or doffing and EVAs. To ensure task and interface designs result in acceptable levels of physical workload, human-in-the-loop evaluation should be conducted early and throughout system design to gather user feedback on perceived exertion and task performance. The Borg RPE is a useful tool for measuring an individual's effort and exertion, breathlessness, and fatigue during physical work. See the Centers for Disease Control and Prevention website for additional information about the Borg RPE.]

10.1.1.6 Situation Awareness (SA)

[V2 5006] Systems **shall** provide the Situation Awareness (SA) necessary for efficient and effective task performance and provide the means to recover SA, if lost, for anticipated levels of crewmember capability and anticipated levels of task demands.

[Rationale: SA refers to the process and outcome of understanding the current context and environment, evaluating that situation with respect to current goals, and projecting how that situation will evolve in the future.

Lack of SA has been associated with numerous accidents and incorrect decisions by flight crews in commercial aviation and in ground-based simulation of spacecraft operations. To maximize SA and optimize operational accuracy and efficiency, designers are to perform a detailed information requirements analysis of all onboard operations and ensure that the crew-vehicle interfaces provide all required information to perform the operation. A useful and effective system design supports the crewmember's ability to rapidly and accurately assess the current situation. Occasional loss of SA is expected in an operational setting where crew may have to unexpectedly move from task to task as events demand. It is important that the system design provides the necessary information, cues, or indicators to help the crewmember easily recover SA. Determination of anticipated levels of crew capability and anticipated levels of task demands is based on a detailed task analysis.]

10.1.2 Controllability and Maneuverability

[V2 10004] The spacecraft **shall** exhibit Level 1 handling qualities (Handling Qualities Rating (HQR) 1, 2 and 3), as defined by the Cooper-Harper Rating Scale, during manual control of the spacecraft's flight path and attitude when manual control is the primary control mode or automated control is non-operational.

[Rationale: Handling qualities are defined as "those qualities or characteristics of [dynamic vehicle control] that govern the ease and precision with which a [user] is able to perform the

tasks required" (Cooper and Harper, 1969). The Cooper-Harper rating scale is a standard method for measuring handling qualities.

Level 1 handling qualities are the accepted standard for manual control of flight path and attitude in military aircraft. Level 1 handling qualities will allow the crew to effectively control the spacecraft when necessary for mission completion or to prevent a catastrophic event. "Non-operational" is defined as automated control system failed or manually disabled. Select manual control scenarios that have to meet Level 1 handling qualities will be defined and scoped with applicable program/project agreement. A scenario includes one or more handling quality-related vehicle control tasks performed during a flight phase under specified conditions. A handling quality-related task is defined as the manual control capability that is being rated with the Cooper-Harper Rating Scale. Each task within a scenario is rated separately and has to meet the appropriate Level 1 handling qualities (handling quality ratings of 1, 2, or 3). Reference NASA-TN-D-5153, The use of pilot rating in the evaluation of aircraft handling qualities, for the Cooper-Harper Rating Scale.

Level 2 or better handling qualities (HQR 1-6) are acceptable during manual control in all other scenarios.]

10.1.3 Standardization

10.1.3.1 Crew Interfaces Standardization

[V2 10005] Crew interfaces **shall** be standardized throughout a system.

[Rationale: The intent of this requirement is to ensure as much commonality and consistency as possible across a system. This facilitates learning and minimizes interface-induced crew error. Standardized/common interfaces are easy to learn and use, because new learning does not have to occur with each new interface. The use of lower level design standards and guidelines that specify the "look" (visual characteristics) and "feel" (style of interaction or operation) can help ensure standardization.]

10.1.3.2 Operations Nomenclature Standardization

[V2 10006] Operational nomenclature **shall** be standardized throughout a system.

[Rationale: It is imperative that space flight operations personnel, including all ground personnel and crewmembers, communicate using common nomenclature that unambiguously and uniquely defines all aspects of crew operations. This includes, but is not limited to, defining the operations, the methods employed by the crew, the equipment, hardware and software items used, and any associated data. This nomenclature is also to be common among all operational products, including inventory, commands, procedures, displays, planning products, reference information, system handbooks, system briefs, mission rules, schematics, and payloads operations products.]

10.1.3.3 Display Standards, Icon Library, and Labeling Plan

[V2 10007] Each program **shall** establish display standards, an icon library, and a labeling plan.

[Rationale: A program-wide display standards document and icon library are to specify and archive characteristics of the display design, including text, graphics, and icons. These products result in cost savings due to less crew training and rework and increased safety due to reduced errors with a familiar design and simplified label verification. A labeling plan is to explicitly specify the characteristics of labels such as font, size, style, color, etc., and includes many example pictures.]

10.1.3.4 Units of Measure

[V2 10008] Units of measure **shall** be consistent across like items.

[Rationale: The intent of this requirement is to ensure the use of one unit across a system for common types of measurements. This minimizes crew training and the potential for conversion errors by crew and ground personnel, which can impact crew and vehicle safety.]

10.1.3.5 Crew Interface Operations Standardization

[V2 10009] Methods of operating crew interfaces **shall** be standardized within and across system elements.

[Rationale: The intent of this requirement is to ensure as much commonality and consistency of crew interface operations as possible across a spacecraft. This facilitates learning and minimizes interface-induced crew error. For example, if the operational design of a toggle switch for one spacecraft is such that up is on and down is off, that operational design should be the same across all spacecraft to avoid the potential for error and reduce training requirements.]

10.1.3.6 Consistent Layout

[V2 10010] Crew interfaces **shall** use consistent control and display layout within and across system elements.

[Rationale: The intent of this requirement is to ensure as much consistency of displays and controls as possible across a spacecraft. Consistent layouts make crew interfaces easy to learn and use, because learning does not have to occur when new displays or controls are encountered within or across the spacecraft.]

10.1.3.7 Displays and Controls Commonality

[V2 10011] Display and control interfaces performing similar functions **shall** have commonality.

[Rationale: The intent of this requirement is to ensure as much commonality of displays and controls as possible across a system. This can be achieved by specifying a standard "look" (visual characteristics) and "feel" (style of interaction or operation) for similar displays and controls. Common displays and controls are easy to learn and use because learning does not have to occur with each display or control.]

10.1.3.8 Consistent Procedures

[V2 10012] Procedures for performing similar tasks **shall** be consistent.

[Rationale: The intent of this requirement is to ensure as much consistency of procedures as possible across a system. This can be achieved by specifying a standard "look" (visual characteristics) and "feel" (style of interaction or operation) for task procedures that are similar. The design of similar procedures should be consistent in terms of structure, format, sequence of steps, and other attributes. Consistent procedures are easy to learn and use because learning does not have to occur when new procedures are encountered. This applies to both the task actions as well as the documentation of procedures such as training materials and instructions.]

10.1.4 Distinction

10.1.4.1 Display and Control Distinctions

[V2 10013] Display and control actions that result in different outcomes **shall** be distinguishable to preclude unintended results.

[Rationale: Display and control actions that have different outcomes are not to be easily confused, else errors result. It is important that display and control actions be distinct, having different visual, haptic, and operational characteristics].

10.1.4.2 Syntax Distinction

[V2 10014] The syntax of any two commands that result in different outcomes **shall** be distinguishable to preclude issuing of the unintended command.

[Rationale: The syntax of commands that have different outcomes should be easy to differentiate. As an example, ending a program or navigating to the end of the data set should be issued by different commands such as "Quit" and "Go to End." Using the command "End" for both could be confusing to a person using a database.]

10.1.5 Use of Cues, Prompts, or Other Aids

10.1.5.1 Use of Cognitive Aids

[V2 10015] The system **shall** provide cognitive aids to reduce the demand on crewmember memory to allow the crew to accomplish their tasks within the required performance parameters.

[Rationale: Design requirements are to ensure that visual, auditory, or haptic cues are used as appropriate to communicate information and options and to remind the crew of expected events or actions. Such cues can speed understanding, maximize productivity, and minimize error. Visual, auditory, and haptic cues can be designed to communicate meaning, an event or condition, or group membership. Examples of reminder cues are pop-up visual alerts or auditory alarms. Examples of option cues are menus or other lists of applicable items.]

10.1.5.2 Cue Saliency

[V2 10016] Cue saliency **shall** be consistent with the importance of the message to be conveyed and urgency of response.

[Rationale: Visual, auditory, and haptic cues are to be highly noticeable when the message being conveyed is important and less noticeable when the message to be conveyed is not as important. The most important or critical alerts are to be highly noticeable, and less important alerts are to be less noticeable. This is done so that, when there is an off-nominal event, the response of the crew is appropriate. Edworthy (1994) provides design guidance for alert tones that convey meaning.]

10.1.6 System Interaction

10.1.6.1 System Health and Status

[V2 10017] The system **shall** provide system health and status information to the crew, either automatically or by request.

[Rationale: Key system parameters and off-nominal system, subsystem, and component trend data are to be available for crew viewing. System health and status information is critical for the crew to retain SA and to have the information necessary to make decisions and troubleshoot problems.]

10.1.6.2 System Messages

[V2 10018] System messages **shall** be specific and informative.

[Rationale: System messages are to be clearly written and understandable, so that they provide all the information necessary to address any issue at hand. Messages that are not specific and informative can cause errors. For example, when performing certain scientific experiments, a

person may need to take certain actions at specific times throughout the experiment. Therefore, it may be necessary to display the actual time elapsed in seconds versus providing a simple on/off indicator. This level of detail is determined as a result of a task analysis of the scientific operation.]

Deleted:

[V2 10019] Requirement merged into [V2 10020].

10.1.6.3 Stale, Missing, or Unavailable Data

[V2 10020] The system **shall** provide unique feedback when a data parameter is stale, missing, or unavailable.

[Rationale: The human operator must be made aware/cued when display systems are no longer receiving live telemetry, and data values may be "stale" or missing. Use of standard color/symbology to represent missing data prevents misinterpretation and errors regarding the system's state.]

10.1.6.4 Control Feedback

[V2 10021] The system **shall** provide a positive indication of crew-initiated control activation.

[Rationale: A positive indication of control activation is used to acknowledge the system response to the control action. For example, a physical detent, an audible click, an integral light, or a switch position may be used to provide a positive indication of control activation.]

10.1.6.5 Maximum System Response Times

[V2 10022] The system **shall** provide feedback to the crew within the time specified in Table 30, Maximum System Response Time(s).

[Rationale: Timely feedback to inputs is critical for crew to feel they are interacting with a responsive system. Slow response times can result in redundant inputs to the system, which can add to crew confusion and errors. A response time of 0.1 s gives the feeling of instantaneous response, and a response time of 1.0 s keeps the user's flow of thought seamless (Miller, 1968; Card, et al., 1991; Nielsen, 1993, 2010).]

Table 30—Maximum System Response Time(s)

System Response	Example	Maximum Time(s)*
Continuous input: cursor and onscreen dynamic elements	Cursor and symbol motion, flight instruments	0.07 (15 Hz)**
Discrete input: Indication of a visual, auditory, or tactile discrete input	On-screen keystroke echo; click or beep; detent/physical feedback	0.1
Update to local element	Display of popup menu	0.5
Display of a requested Graphical User Interface (GUI)	Calling up a new display or display component	1.0
Display of updated data on crew command of a state change	Status of “on” when commanded on; status of “open” when commanded open	1.0
Feedback for commands that cannot be completed within 1 second: Indication that a command or process is in progress Status of the command/process after request completed	 A progress bar showing time remaining or a progress message After request is completed – status message of success/fail/unknown	 1.0 1.0

** Note that systems with “Short time to effect” scenarios may require faster response times, as determined in the task analysis.*
*** Polling rate, DPI, and screen refresh rate are factors that affect cursor and screen dynamic elements*

10.1.6.6 LED Indicator Light Characteristics

[V2 10201] The system **shall** implement LED indicator lights that meet the characteristics shown in Table 31, LED Indicator Light Characteristics.

[Rationale: This requirement promotes consistency across LED indicators and the use of color for alerts, reducing the risk of misinterpretation and error. Care should be taken to ensure colors are distinguishable (e.g., yellow is not confusable with green).]

Table 31—LED Indicator Light Characteristics

Type	Meaning
Flashing Red	Emergency
Red	Warning, Failed
Yellow	Caution, Off-nominal State, Trip
Green	Power, On, Enabled, Good State

10.1.7 Electronic Procedures

10.1.7.1 Current Procedure Step

[V2 10023] The system **shall** indicate to the crew which step in the electronically displayed procedure is currently being executed.

[Rationale: The current procedure line is to be highlighted in some way to prevent the crew from missing steps, which can result in errors and wasted time. In addition, if the crew becomes distracted or called to support a different task and needs to be able to come back to the last completed step, devices/markers should be available to support resuming the interrupted procedure.]

10.1.7.2 Completed Procedure Steps

[V2 10024] The system **shall** indicate to the crew which steps in the electronically displayed procedure have been completed.

[Rationale: This requirement prevents the crew from re-executing steps in a procedure by highlighting the steps that have been completed. Completed steps need to be highlighted in some way to prevent the crew from re-executing steps, which can result in errors and wasted time.]

10.1.7.3 View of Procedure Steps

[V2 10025] The system **shall** provide a method for viewing prior and future steps in the electronically displayed procedure.

[Rationale: The crew is to be able to look back in procedures to see what has been completed and to be able to look forward in procedures to see upcoming steps.]

10.1.7.4 Procedure Flexibility

[V2 10026] The system **shall** provide a method for the crew to make real-time insertion, deletion, and rearrangement of electronic procedures.

[Rationale: During the course of a mission, the crew may need to make real-time modifications of procedures. In addition, performance can often be more effective if the sequence of procedures remains flexible throughout the mission. For lunar robotic activities, a priori information (resolution of maps, simulation of mobility over lunar regolith) of the lunar surface (or lack thereof), plans, and timelines for activities will be subject to change in real time. Real-time replanning of lunar surface activities will be necessary, and corresponding electronic procedures will need to be rearranged and assessed accordingly.]

10.1.8 Error Prevention and Recovery

10.1.8.1 Inadvertent Operation Prevention

[V2 10027] Control systems **shall** be designed to prevent inadvertent operation.

[Rationale: This requirement allows for the design to preclude inadvertent operation which would cause a critical or catastrophic event. For example, accidental activation by bumping can be prevented by the use of guards, covers, and physical separation from other controls. Accidental activation of commands using a computer display can be prevented with an "arm-fire" mechanism. This requirement is not intended to prevent operators from initially selecting the wrong control.]

10.1.8.2 Inadvertent Operation Recovery

[V2 10028] Control systems **shall** allow for recovery from inadvertent operation and accidental changes in system status.

[Rationale: This requirement allows for the design of mechanisms for fixing a control input. If there has been an inadvertent input or a mistake in input, design requirements are to ensure the crew can recover with minimal impact.]

10.2 Layout of Displays and Controls

10.2.1 Location

10.2.1.1 Display and Control Location and Design

[V2 10030] Displays and controls **shall** be designed and located so that they are operable to the required degree of accuracy in expected operating positions and conditions.

[Rationale: Displays need to be visible and controls need to be within the functional reach envelope and operable to the required degree of accuracy (determined by a task analysis). This applies to all vehicle conditions (e.g., g-loads and vibration), suit conditions (e.g. unsuited, suited unpressurized, suited pressurized), and expected crew postures (e.g., standing, seated, restrained, and unrestrained). Controls can include display devices such as touchscreens. This requirement is intended to encourage the design of a layout that optimizes operations in the cockpit.]

10.2.1.2 High Priority Displays and Controls

[V2 10031] Emergency, critical, important, and most frequently used displays and controls **shall** be located in the most prominent crew viewing and operating zones.

[Rationale: During the design process, tradeoff of location of critical controls is to be made; however, all controls are required to be within the functional reach envelope of the crew. The most important or critical displays and controls are to be located in the most prominent, noticeable locations and also be quickly accessible. This helps ensure quick processing and reaction to important displays and controls. Criticality is be determined through a detailed task analysis.]

10.2.2 Display and Control Grouping

[V2 10032] Displays and controls **shall** be grouped according to purpose or function.

[Rationale: This requirement is intended to encourage the design of a layout that optimizes operations in the cockpit. This would help ensure that displays and controls are easily accessible when used together. Grouping is determined through a detailed task analysis.]

10.2.3 Display-Control Associations

10.2.3.1 Display-Control Relationships

[V2 10033] All display-control relationships **shall** be logical and explicit.

[Rationale: The relationship between displays and controls needs to be obvious. This relationship can be indicated by relative location, color coding, and labeling. This requirement is intended to encourage the design of a layout that optimizes operations in the cockpit. This helps ensure that it is easy for the crew to understand how displays and controls are related without additional instructions or explanations.]

10.2.3.2 Display and Control Movement Compatibility

[V2 10034] Displays **shall** be compatible with control movement, e.g., control motion to the right is compatible with clockwise roll, right turn, and direct movement to the right.

[Rationale: The movement of a control is to have an intuitive correspondence to the movement on a display. If displays are overlaid on a visual (camera or direct view) scene, control movement is relative to this point of view. This helps ensure easy understanding of relations between controls and displays.]

10.2.3.3 Display and Control Sequence of Use

[V2 10035] Displays and controls **shall** be arranged in relation to one another according to their sequence of use.

[Rationale: Rapid, error-free operation and quick comprehension of system status are all improved by well-designed co-location of related controls. Displays and controls that are used in sequence are to be placed accordingly.]

10.3 Displays

10.3.1 Display Design

10.3.1.1 Display Identifying Features

[V2 10036] Displays **shall** have identifying features (such as location, size, shape, and color) that allow the crew to correctly navigate, locate, and identify the display in a timely manner.

[Rationale: Display characteristics are to make displays easy to identify to prevent mode confusion and maintain SA.]

10.3.1.2 Display Area

[V2 10037] The system **shall** provide the display area to present all critical task information within a crewmember's field of regard.

[Rationale: To ensure that critical tasks can be performed quickly, easily, and accurately, especially during critical mission phases, it is important to avoid scrolling or switching among several display pages and to avoid excessive head or body movement by the crewmember to view several displays. Criticality should be determined through a detailed task analysis.]

10.3.2 Display Content

10.3.2.1 Display Interpretation

[V2 10038] Displays **shall** be accurately interpretable within the time required to meet mission needs.

[Rationale: To increase the user's accuracy and response time, displays need to provide the required information in a manner that is compatible with the operating environment and the decision to be made.]

10.3.2.2 Display Readability

[V2 10039] Displays **shall** be readable by the crewmember from the crewmember's operating locations and orientation.

[Rationale: Design of the displays is to be appropriate for the possible viewing angles, distances of the crew, and the expected environmental conditions during use (such as high acceleration and/or vibration). This will ensure that the information on the displays will be accurately and completely read from all operating locations and orientations.]

10.3.2.3 Display Information

[V2 10040] Information displayed **shall** contain only what is needed for the crew to maintain SA, diagnose, make decisions, plan responses, and perform the required tasks.

[Rationale: Too much information increases visual clutter and leads to increased task completion times. Lack of relevant information impacts SA and increases the chances of an error. Appropriate display content can be determined by task analysis.

10.3.2.4 Display Information Flow

[V2 10042] Information displayed **shall** be grouped, arranged, and located to support task flow.

[Rationale: The information displayed are to be grouped, arranged, and located based on frequency of use, sequence of use, and criticality to support the task flow. This helps ensure that the task is accomplished in a timely manner. Task flow is determined through a detailed task analysis.]

10.3.2.5 Display Navigation

[V2 10043] Display navigation **shall** allow the crewmember to move within and among displays without loss of SA and in a timely manner.

[Rationale: Unnecessary steps in navigation may increase task time and may reduce a crewmember's SA related to task completion. In general, to make navigation more transparent, it is recommended to have a shallow navigational structure for navigation instead of a deep structure.]

10.3.2.6 Display Nomenclature

[V2 10044] The nomenclature for each item or process **shall** be self-explanatory and direct the crew to the function or usage of the item.

[Rationale: Item and process names are to be easy to understand and to remember. This limits the time spent on recognizing and understanding names. Also, this limits the training needed to understand the nomenclature of the items.]

10.3.2.7 Display Coding Redundancy

[V2 10045] For critical information and critical tasks when color is used to convey meaning, the system **shall** provide an additional cue.

[Rationale: Redundant coding is required to accommodate the variability in people's capability to see color under different lighting conditions and to increase the saliency of identification markings. Redundant cues can include labels, icons, and speech messages.]

10.3.2.8 Measurement Units

[V2 10046] Units of measure **shall** be displayed with their corresponding values.

[Rationale: Measurement units are to be identifiable with the correct magnitude and scale. This ensures correct decision making when comparing or using these units in some other way.]

10.3.3 Visual Display Devices

10.3.3.1 Visual Display Legibility

[V2 10047] Displays **shall** be legible in the viewing conditions expected during task performance.

[Rationale: Legibility includes both text elements, as well as meaningful graphic elements such as symbols, icons, and maps, and is important for the timely and accurate processing of information. Legibility depends upon display properties such as resolution and contrast, as well as text properties such as font contrast, color, and size, background color and texture, as well as the visual capabilities of the crew and the ambient illumination. In addition, the possible viewing angles, distances of the crew from displays, the presence of a visor, and the expected environmental conditions during use (such as high acceleration and/or vibration) need to be considered.]

10.3.3.2 Visual Display Parameters

[V2 10048] Displays **shall** meet the visual display requirements in Table 32, Visual Display Parameters.

[Rationale: Legibility of displayed information is important for the timely and accurate processing of information. To ensure legibility and visual quality, displays are to have sufficient spatial and temporal resolution, brightness, luminance contrast, and color gamut, taking into account the ambient illumination, glare, reflections, vibration, and distance, position, and orientation of the display relative to the crewmember.]

Table 32—Visual Display Parameters

Metric	Minimum	Maximum	Context	Notes
Peak white luminance	25 cd/m^2	--	Emissive displays	≥100 cd/m^2 preferred
Ambient contrast ratio	10	--		Includes ambient illumination
Color gamut area	0.17	--	Color displays	Fraction of CIE 1976 u'v' chromaticity space
Viewing angle	-45 deg	+45 deg		Four-point viewing angle (left, right, up, down), contrast and color gamut criteria met
Spatial resolution	32 pixels/deg	--	Image and video displays	
Frame rate	60 Hz	--	Video displays	
Moving edge blur	--	15 ms		Using metric GET (preferable) or BET; use average of five equal lightness levels, including white and black
Number of colors	2^{24} (1,627,716)	--	Image and video displays	

Metric	Minimum	Maximum	Context	Notes
	2^{12} (4,096)	--	Text and graphics displays	
Number of gray levels	2^{8} (256)	--	B/W image and video displays	
Except where noted, metrics are as defined as in International Committee on Display Metrology (ICDM), Display Measurement Standard (DMS 1.0), or Video Electronics Standards Association (VESA) Flat Panel Display Measurements (FPDM 2.0). Further details on metrics may be found in chapter 10, Crew Interfaces, of the HIDH.				

10.3.3.3 Visual Display Character Parameters

[V2 10049] Displays **shall** meet the visual display character requirements in Table 33, Visual Display Character Parameters.

[Rationale: Character (text) elements are a critical component of displayed information, and the legibility of characters is important for timely and accurate processing of information. To ensure legibility of text, characters are to have sufficient luminance contrast and size, taking into account the ambient illumination, glare, reflections, vibration, and distance, position, and orientation of the display relative to the crew. Character contrast refers to the ratio of character luminance to background luminance. Font height in degrees refers to the angle subtended at the eye by the height of an upper-case letter in the font.]

Table 33—Visual Display Character Parameters

Metric	Minimum	Notes
Character contrast	0.2 *(Weber Contrast)*	Includes ambient illumination
Character height	0.25 deg	≥0.4 deg preferred. (0.25 deg is 10-point type at 32 in)

10.3.3.4 Display Font

[V2 10050] Font size and type **shall** be selected to ensure acquisition, readability, and interpretability of visual displays.

[Rationale: Choice of text font and size can have a large impact on legibility and is important for the timely and accurate processing of information. While a minimum character height may be acceptable in some circumstances, in general, the size required depends on the task. For example, the smallest font sizes are acceptable for occasional scrutiny, but comfortable reading relies on larger font sizes; rapid comprehension of critical displays relies on larger fonts still. All font size choices depend on the visual capabilities of the crew, including visual acuity and ability to accommodate. In addition, the possible viewing angles, distances of the crew from displays, and the expected environmental conditions during use (such as high acceleration and/or vibration) need to be considered.]

10.3.4 Audio Displays

10.3.4.1 General Audio Displays

10.3.4.1.1 Intelligibility of Electronically Stored Speech Messages

[V2 10052] Electronically stored speech messages from audio displays **shall** have 100% intelligibility and discriminability between the ensemble of different messages the audio display is programmed to produce (as measured under realistic background noise conditions and at locations where the display will be used).

[Rationale: Some audio displays and alarms express their messages using electronically stored speech. The consequences of misunderstanding these messages can result in lost time and possible missed or false alarms and can ultimately be a critical safety issue.]

10.3.4.1.2 Sound Pressure Level

[V2 10053] The system **shall** provide SPLs above background noise and compliant with acoustic limits to ensure audio display usability.

[Rationale: Auditory displays are to be audible as well as interpretable by the crew. This helps make sure that appropriate responses are taken as needed.]

10.3.4.1.3 Sound Distortion Level

[V2 10054] The system **shall** provide audio signals with a minimal level of distortion and an appropriate frequency range to ensure usability of the audio display.

[Rationale: Auditory displays are to be audible as well as interpretable by the crew. This helps make sure that appropriate responses are taken as needed.]

10.3.4.1.4 Distinguishable and Consistent Alarms

[V2 10055] The system **shall** provide distinguishable and consistent alarms to ensure audio display usability.

[Rationale: Different types of alarms (different enough to be easy to identify) are to be used. To avoid confusion, the alarm system is to use a distinctive signal to ensure appropriate responses from the crew.]

10.3.4.2 Sound Characteristics

10.3.4.2.1 Audio Display Sound Level

Units of measure noted below can be found in Appendix B.

[V2 10056] The system **shall** produce non-speech auditory annunciations with an SPL that meets at least one of the following criteria:

a. Using measurements of A-weighted sound levels (ISO 7731:2003(E), Ergonomics – Danger signals for public and work areas – Auditory danger signals, method a in section 5.2.2.1), the difference between the two A-weighted SPLs of the signal and the ambient noise is greater than 15 dBA (LS,A to LN,A > 15 dBA). This method must be used for alarms intended to wake sleeping crewmembers, with the loudspeaker alarm volume adjusted to its minimum setting.

b. Using measurements of octave band SPLs (ISO 7731:2003(E), method b in section 5.2.3.1), the SPL of the signal in one or more octave bands is greater than the effective masked threshold by at least 10 dB in the frequency range from 250 Hz to 4,000 Hz (LSi,oct to Lti,oct > 10 dB).

c. Using measurements of 1/3-octave band SPLs (ISO 7731:2003(E), method c in section 5.2.3.2), the SPL of the signal in one or more 1/3-octave bands is greater than the effective masked threshold by 13 dB in the frequency range from 250 Hz to 4,000 Hz (LSi,1/3oct to LTi,1/3oct > 13 dB).

[Rationale: To get the attention of the crew, alarms are to be louder than the background noise. The masking threshold is the SPL of a sound one needs to hear in the presence of a masker signal. Having the audio displays 13 dB above the masked threshold ensures that the crew can hear them, regardless of the background noise.]

10.3.4.2.2 Reverberation Time

[V2 10057] The system **shall** provide a reverberation time of less than 0.6 seconds within the 500-Hz, 1-kHz, and 2-kHz octave bands.

[Rationale: This 0.6 s reverberation time requirement limits degradation of speech intelligibility to no more than 10% for ideal signal-to-noise ratios of >30 dB or 15% for a signal-to-noise ratio of 3 dB (Harris, 1997).]

10.3.4.2.3 Frequency

[V2 10058] Frequency content of auditory alarms **shall** correspond to maximal human sensitivity (200 Hz to 4 kHz).

[Rationale: Auditory alarms are to use frequencies that are appropriate for human hearing. Using frequencies below or above those appropriate for human hearing makes auditory displays inaudible for the crew.]

Deleted:

[V2 10059] Requirement merged into [V2 10056].

10.3.5 Labels

10.3.5.1 Label Provision

[V2 10060] Labels **shall** be provided, as necessary, for the crew to identify items, interpret and follow nominal and contingency procedures, and avoid hazards.

[Rationale: Crew interface items are to have identifiers (labels) to aid in crew training and error-free operation. Labels reduce memory load and improve accuracy of tasks. This includes identification of emergency equipment and procedures.]

10.3.5.2 Label Standardization

[V2 10061] Labels **shall** be consistent and standardized throughout the system.

[Rationale: Standardization of labels reduces learning and recognition times, which is especially important in emergencies. Specific labels are always to be used for the same type of item, and similarities are reflected by using similar nomenclature on the label.]

10.3.5.3 Label Display Requirements

[V2 10062] Labels **shall** meet the requirements of visual displays (section 10.3.3, Visual Display Devices, in this NASA Technical Standard), except font height ([V2 10066] Label Font Height in this NASA Technical Standard).

[Rationale: The requirements that apply to visual displays also apply to labels in all aspects such as font size, colors, contrast, and legibility. By meeting requirements, crew performance across systems is enhanced.]

10.3.5.4 Label Location

[V2 10063] Labels **shall** be positioned on or directly adjacent to the item they are labeling.

[Rationale: Labels that are placed far from items they intend to label can result in the crew missing their association or misidentifying items. This can slow down task performance and may cause errors.]

10.3.5.5 Label Categories

[V2 10064] Labels **shall** be categorized by type, e.g., safety, procedure, and identification, with each label type having standardized, visually distinct characteristics.

[Rationale: Labels are to be categorized as a certain type and thus be identified as being part of that category. Providing similar characteristics for labels of similar type can improve identification and interpretation of labels.]

10.3.5.6 Label Distinction

[V2 10065] Labels **shall** be easily recognizable and distinguishable from other labels.

[Rationale: Each label is to be distinctive enough to be recognized as an individual label. Individually distinguishable labels reduce the possibility of errors and confusion and save crew time.]

10.3.5.7 Label Font Height

[V2 10066] Font height of 0.4 degrees or greater **shall** be used on labels.

[Rationale: Font height in degrees refers to the angle subtended at the eye by the height of an uppercase letter in the font. Labels are to use a large enough font size to ensure legibility. Small fonts can make labels difficult to perceive by the crew, consequently increasing the time needed for item identification. The font height given is a minimum. The font may have to be larger for readability when taking into account the ambient illumination, glare, reflections, vibration, position, and orientation of the label relative to the crew.]

10.4 Control Design

10.4.1 Control Shape

[V2 10067] The shape of a control **shall not** interfere with ease of control manipulation.

[Rationale: The shape chosen for a control is to facilitate use, rather than making it more difficult to use. This makes sure that the operation of controls is easy and does not cause fatigue or time delays.]

10.4.2 Identification

10.4.2.1 Control Identification

[V2 10068] Controls that are intended for out-of-view operation **shall** be spatially or tactually distinct from one another.

[Rationale: When the crew inadvertently operates the wrong control, serious errors can result. Controls designed to be out of view while being operated are to be spaced or shaped/textured such that the control can be identified with a pressurized gloved hand without line of sight. This would include controls for vehicle operation, as well as other controls, e.g., seat positioning). It has been shown that human operators can use simple tactile coding to reliably distinguish between items.]

10.4.2.2 Emergency Control Coding

[V2 10069] The system **shall** provide coding for emergency controls that are distinguishable from non-emergency controls.

[Rationale: When the crew inadvertently operates the wrong control, serious errors can result. Controls designed to be out of view while being operated are to be spaced or shaped/textured such that the control can be identified with a pressurized gloved hand without line of sight. This would include controls for vehicle operation, as well as other controls, e.g., seat positioning. It has been shown that human operators can use simple tactile coding to reliably distinguish between items.]

10.4.3 Access

10.4.3.1 Control Size and Spacing

[V2 10070] The size and spacing of controls **shall** be optimized for operation by the expected body part, e.g., finger, hand, foot, and expected clothing.

[Rationale: The size of a control is to be appropriate for the way it is intended to be used. Controls operated by finger are to be smaller than controls operated by hand to ensure optimal manipulation. Incorrectly sized controls may cause errors during control operation.]

10.4.3.2 Control Arrangement and Location

[V2 10071] The arrangement and location of functionally similar or identical controls **shall** be consistent throughout the system.

[Rationale: Controls with similar functions are to have similar properties, specifically location and arrangement for easy identification. This helps reduce the time necessary to find and operate a control.]

10.4.3.3 Control Proximity

[V2 10072] Controls used by a restrained or unrestrained crewmember **shall** be located within the functional reach zones of the crew.

[Rationale: A control that is required to be used at any time in a task is to be readily available and reachable by the crew to ensure smooth operation. Controls that are not readily available or not reachable can increase the time to perform operations.]

10.4.3.4 Control Operation Supports and Restraints

[V2 10073] The system **shall** provide body or limb supports and restraints that enable accurate crew control of applicable interfaces and prevent inadvertent control inputs during expected microgravity, acceleration, and vibration conditions.

[Rationale: During expected microgravity acceleration and vibration conditions, the accuracy of gross limb movements is compromised, and thus control action under these conditions is to be limited to hand and wrist motions alone. Furthermore, accidental actuation of controls can result in errors and reduce safety.]

10.4.4 Operating Characteristics

10.4.4.1 Control Operating Characteristics

[V2 10074] Controls **shall** have operating characteristics, e.g., control type, forces, response rate, response latency, tactile feedback, to allow the crew to make the controlled item respond with the required levels of accuracy, precision, and speed.

[Rationale: Controls are to have the appropriate properties to allow for error-free operation. Controls can be tested to make sure that their speed, response to action, and other properties are optimal for their intended operational conditions. Control operating characteristics of vehicle is evaluated in conjunction with handling qualities, controllability, and maneuverability.]

10.4.4.2 Control Input-Response Compatibility

[V2 10075] Controls **shall** be compatible with the resulting system response.

[Rationale: The relation between input direction and system responses is to be intuitive and easy to perceive. This makes sure that when a control is used, system response is easy to link and conforms to crew expectations. Operator confusion may result if system responses are not compatible with input directions.]

10.4.4.3 Control Latency

[V2 10076] The system **shall** provide controls such that the crew is unimpeded by the time lag between the operation of a control and the associated change in system state.

[Rationale: State changes associated with the operation of a control are to be easy to link together in time. If the two events occur with a time lag, it is difficult to identify whether the operation of the control had the intended effect.]

10.4.4.4 Control Resistive Force

[V2 10077] Control resistive force **shall** prevent unintended drifting or changing of position.

[Rationale: Controls are not to be capable of being accidentally actuated by unintended actions. This reduces the number of errors and increases safety.]

10.4.4.5 Detent Controls

[V2 10078] Detent controls **shall** be provided when control movements occur in discrete steps.

[Rationale: Mechanisms that provide control feedback to crewmembers are to be based on the amount of the movement applied to the control. This is usually provided using auditory and haptic feedback.]

10.4.4.6 Stops Controls

[V2 10079] Stops **shall** be provided at the beginning and end of a range of control positions, if the control is not required to be operated beyond the end positions or specified limits.

[Rationale: Limits within which controls can be operated are to be obvious to the crew by the provision of easy-to-perceive stops in the mechanism of the controls. Failure to include stops can result in increased operations time, as the operator may needlessly continue to turn a dial after it has reached its functional end point.]

10.4.5 Command Confirmation

[V2 10080] Crew confirmation **shall** be required before completing critical, hazardous, or destructive commands.

[Rationale: Critical commands are to be prevented from being accidentally issued, which can be accomplished by requesting confirmation from the crew, thus reducing the chance of errors.]

10.4.6 Suited Use of Controls

10.4.6.1 Suited Control Operations

[V2 10081] Controls to be used by suited crewmembers **shall** be operable by a suited crewmember.

[Rationale: Controls that are intended to be used by suited crewmembers are to have the appropriate features for suited use. For instance, these controls may have to be adjusted to increase haptic feedback when used with gloved hand to make sure that the speed and accuracy of suited use is comparable to unsuited performance.]

10.4.6.2 Suited Control Spacing

[V2 10082] Controls to be used by suited crewmembers **shall** be spaced such that they can be operated by a suited crewmember without inadvertent operation of adjacent controls.

[Rationale: Control layout is to take into account the fact that pressurized suited operators cannot operate with the same precision and dexterity as lightly clothed crewmembers in expected conditions, e.g., g-loads, vibration, and acceleration. Insufficient spacing may lead to inadvertent operation of an adjacent control.]

10.5 Communication Systems

Communication systems include information (e.g., telemetry) provided to and from the crew by way of voice, text, or video.

10.5.1 Communication System Design

[V2 10083] Communication systems **shall** be designed to support coordinated and collaborative distributed teamwork.

[Rationale: To ensure optimal team collaboration in exploration missions, it is essential to design communication systems that provide an accurate, comprehensive, real-time understanding of the current situation and to implement tools that enable team members across the multi-team system of crew and ground to communicate and collaborate effectively. This is particularly critical when teams are operating in the presence of communication transmission delays and intermittent transmission. Communication systems process information to and from the crew and may consist of the following media: voice, video, text, and data.]

10.5.2 Communication Capability

[V2 10084] The system **shall** provide the capability to send and receive communication among crewmembers, spacecraft systems, and ground systems to support crew performance, behavioral health, and safety.

[Rationale: Communication capabilities are necessary to enable information exchange to accomplish tasks efficiently, to maintain crew physical and behavioral health, and to ensure crew safety. The capability to send and receive information among crew (IVA and EVA), Earth-based mission control, orbiting vehicles, planetary habitats, rovers, robotic systems, and other systems is to be supported as required by the task analysis for the particular Design Reference Mission (DRM). Communications can include voice, text, video, telemetry, and other formats, depending on the needs as determined by a task analysis.]

10.5.3 Audio Communications

10.5.3.1 Communication Speech Levels

[V2 10085] Audio communication systems **shall** allow crew to communicate with one another and with the ground at normal speech levels and with expected background SPLs.

[Rationale: When crewmembers and ground personnel use the voice communication systems, they are to be able to do so using their normal level of speech, rather than having to raise their voices to higher levels. Higher voice levels distort sounds, make speech less intelligible, and are more strenuous to keep up for longer periods.]

10.5.3.2 Communication Operational Parameters

[V2 10086] The audio communication system **shall** provide intelligible speech by addressing system operational parameters, including frequency, dynamic range, noise cancelling and shields, pre-emphasis, and peak clipping.

[Rationale: Communication is optimized by taking into account all parameters needed for speech intelligibility. For example, noise cancelling can enable normal voice levels.]

10.5.3.3 Communication Environmental Parameters

[V2 10087] The audio communication system **shall** provide intelligible speech by addressing appropriate background sound levels and architectural acoustical characteristics for both transmitter and receiver area.

[Rationale: Background noise, reverberations, and other acoustic phenomena are not to interfere with crew communications. High levels of background noise can make audibility of speech difficult; similarly, high reverberations interfere with speech intelligibility.]

10.5.3.4 Communication Controls and Procedures

[V2 10088] To ensure intelligibility, audio communications **shall** address operating controls and procedures, including volume, squelch, natural language, acknowledgement feedback, and muting.

[Rationale: Appropriate controls and procedures are to be employed to increase intelligibility. Procedures are to use natural language; there are to be ways to acknowledge receiving a message or muting a message. This improves communications by reducing frustration and confusion.]

10.5.3.5 Communication Transmitter and Receiver Configuration

[V2 10089] To ensure intelligibility, audio communications **shall** address transmitter and receiver configuration, e.g., headsets, microphones, air conduction, and bone conduction.

[Rationale: Transmitters and receivers are to have optimal properties to support good communication. By having appropriate headsets and microphones, the crew can send and receive high-quality voice and audio.]

10.5.3.6 Audio Communications Quality

[V2 10090] The audio communication system **shall** provide speech quality that does not impact crew performance.

[Rationale: Audio communication is to be of the appropriate quality to help and not impede task completion. If procedures, for example, cannot be heard appropriately, it is likely that errors are going to occur.]

10.5.3.7 Speech Intelligibility

[V2 10091] For critical communications, the system **shall** ensure 90% English word recognition, using ANSI/ASA S3.2-2009, Method for Measuring the Intelligibility of Speech over Communication Systems.

[Rationale: Voice communication is to be perceived accurately. If messages are perceived with errors or low precision, important information may be missed; therefore, crew may make errors in tasks, and their safety may be jeopardized. Note: [V2 10091] Requirement Speech Intelligibility in this NASA Technical Standard is not meant to apply to speech recognition software.]

10.5.3.8 Private Audio Communication

[V2 10093] The system **shall** provide the capability for private audio communication with the ground.

[Rationale: Private communication capabilities are to exist for the crewmember to discuss topics such as family, health, and medical issues with the ground in private.]

10.5.4 Video Communications

Video communications systems are communications channels designed to convey visual information such as camera video, animated graphics, and photographic images.

10.5.4.1 Video Communications Visual Quality

[V2 10094] Video communications **shall** employ digital encoding or alternate coding of equivalent visual quality.

[Rationale: The quality of the video communications is to be appropriate for correct information transfer. Bad image quality can be misinterpreted, can cause communication problems, and can increase time needed to accomplish tasks.]

10.5.4.2 Video Communications Spatial Resolution

[V2 10095] Video communications **shall** provide sufficient spatial resolution (width and height in pixels) to accomplish relevant tasks.

[Rationale: The resolution of video is to be appropriate for the task that it is intended to serve, so that errors related to artifacts of low resolution and delays in task completion are avoided.]

10.5.4.3 Video Communications Temporal Resolution

[V2 10096] Video communications **shall** provide sufficient temporal resolution (frames/s) to accomplish relevant tasks.

[Rationale: The temporal resolution of a communication is to be appropriate so as to perceive human speech, motion, and object motion through the video. Inappropriate resolution can make these more difficult or impossible, thus causing difficulties in information transfer.]

10.5.4.4 Video Communications Color and Intensity

[V2 10097] Video communications **shall** provide sufficient color and intensity levels to accomplish relevant tasks.

[Rationale: Color and intensity are to be transmitted appropriately. Inappropriate color and intensity in video communication may cause misidentification and misinterpretation of information, thus causing errors and problems in task completion.]

10.5.4.5 Video Communications Bit Rate

[V2 10098] Video communications systems **shall** support bit rates high enough to ensure that compression artifacts are as low as reasonably achievable.

[Rationale: The compression method and level used for video communication are not to introduce excessive visible artifacts. Artifacts can hinder information transfer and can cause communication difficulties.]

10.5.4.6 Audio-Visual Lag Time

[V2 10099] Communications systems that carry sound and video that are intended to be synchronized **shall** ensure that the sound program does not lead the video program by more than 15 ms or lag the video program by more than 45 ms.

[Rationale: The video and associated audio time lag can cause perceptual difficulties for the crew. When listening to human speech, even small lags between audio and video can be noticeable and disturbing.]

10.6 Automated and Robotic Systems

Automation is the use of machines or computers to perform tasks for the purpose of reducing crew workload, increasing productivity, or decreasing risk in operations that cannot be safely performed by the crew. A special category of automated systems is the mobile machine, which includes rovers, robotic agents, and mobile assistants, operating in space or on planetary surfaces.

10.6.1 Automated and Robotic System Provision

[V2 10100] Automated or robotic systems **shall** be provided when crew cannot reliably, safely, or efficiently perform assigned tasks.

[Rationale: Systems are to have automated or robotic solutions that can perform tasks where (1) crew cannot respond as quickly, precisely, or repeatedly as necessary; (2) crew cannot physically complete the task; or (3) using automation/robotic solutions reduces crew risk exposure (e.g., high radiation environments, limited life support availability).]

10.6.2 Automated and Robotic System Safety

[V2 10101] Automated and robotic systems **shall** include safeguards to prevent mission degradation, equipment damage, or injury to crew.

[Rationale: Automated and robotic systems are to have preventive/safety measures in place such as mechanical constraints, threshold set points, automatic shutoffs, and emergency stops to ensure that they cannot negatively impact the mission, hardware, or crew health and safety. Robotics systems with internal safety checks that recognize and avoid unsafe conditions, e.g., excessive speed, force, torque, are more likely to achieve mission success. This applies to robotic systems both inside and outside spacecraft. For more information regarding this subject, see Chapter 10, Crew Interfaces, of the HIDH.]

10.6.3 Robotic Control Stations – Common and Consistent

[V2 10102] For a given robotic system, operator control stations **shall** be common and consistent, independent of physical location, e.g., on Earth, in space, on the lunar surface, or on a planetary surface.

[Rationale: The intent of this requirement is to ensure that robotic control stations are the same to the greatest extent possible, especially when the tasks are the same, regardless of their physical location. This includes all operator hardware and software interfaces, as well as physical layout and design. Control stations for a given system may exist in different locations, such as on Earth, in space, on the lunar surface, or on a planetary surface. Likewise, a robotic system may be controlled or monitored by multiple operators simultaneously. It is important that operators be able to transfer skills and share knowledge in real time without losing SA or experiencing negative training. Limitations may be present when real estate or other potential constraints exist, i.e., control of a robot from an EVA suit.]

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[V2 10103] Requirement merged into [V2 10104].

10.6.4 Automation Levels

[V2 10104] Crew interfaces to automated and robotic systems **shall** support the appropriate level(s) of automation to accomplish the task effectively.

[Rationale: Design requirements are to ensure that different levels of automation are available, depending on which level best suits the task/situation. While higher levels of automation can result in increased crew performance (e.g., less errors) and lower workload, they can also result in poorer SA and loss of crew skills (Onnusch, Wicken, Li, and Manzey, 2013). This tradeoff should be taken into consideration when designing automated and robotic systems. Task analysis in conjunction with function allocation evaluations should determine the appropriate level of automation, and a trade analysis should be conducted. Systems are not to be so reliant on automation that human operators cannot safely recover from emergencies or operate the system manually if the automation fails.]

10.6.5 Automation Level Status Indication

[V2 10105] Crew interfaces to automation **shall** provide information on the status of the automation, including when the system changes between levels of automation.

[Rationale: The intent of this requirement is to ensure that operators are always able to ascertain the status of automated processes in an effort to maintain mode awareness. It needs to be clear whether the human operator or the system is supposed to perform a particular task at a specific time. The operators need to be able to determine and affect what level of automation the system is operating in, as well as which processes are being automated. Analysis will determine

cases where alerting may be required when automation takes control from human operators or switches to a higher level of automation.]

10.6.6 Robotic System Status

[V2 10106] Crew interfaces to robotic assets **shall** provide information on the status of the robotic asset, including health, past and intended future actions, procedural information, and the ability of the robotic asset to comprehend and accept operator commands.

[Rationale: The crew need to have constant awareness of the status of a robotic asset to allow sufficient time for deliberate procedural modifications or emergency actions.]

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[V2 10107] Requirement merged into [V2 10101].

10.6.7 Automated and Robotic System Operation – with Communication Limitations

[V2 10108] Automated and robotic systems **shall** be capable of receiving and sending commands and performing tasks in the presence of a communication latency and intermittent transmission related to remote operations.

[Rationale: Automated and robotic systems need to be designed such that any delays associated with remote mission operations are accounted for to ensure efficient and effective performance. Automation should be sufficiently autonomous to function without continuous human supervision. Time delays between control inputs and system responses can cause problems, and mechanisms need to be in place to ensure that the system functions as expected. Consideration should be given to telerobotic software and hardware that may be required to operate robotic systems in the presence of such time delays, intermittent transmission of data, or when the operator and robot are not co-located.]

10.6.8 Automated and Robotic System Shutdown Capabilities

[V2 10109] Crew interfaces **shall** provide the ability to shut down automated and robotic systems.

[Rationale: The system is to allow the crew the ability to shut down automated or robotic systems if it is determined that these systems present a risk or are no longer providing the intended benefit. The crew is to remain in ultimate control of the vehicle at all times throughout a mission.]

10.6.9 Automation and Robotics Override Capabilities

[V2 10110] Crew interfaces **shall** provide the ability to override automated and robotic systems.

[Rationale: The system is to allow the crew the ability to override automated or robotic systems if it is determined that these systems present a risk or if redirection of activities is needed. The system is to provide consequence information and guidance to the operator for an override of automated and robotic systems. The crew is to remain in ultimate control of the vehicle at all times throughout a mission.]

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[V2 10111] Requirement merged with [V2 10112].

10.6.10 Crew Interfaces to Robotic Systems - Frames of Reference

[V2 10112] Crew interfaces to robotic systems **shall** be designed to enable effective and efficient coordination of or shifting between multiple frames of reference.

[Rationale: Coordination of or shifting between different frames of reference in a human-robotic task is to be intuitive to the crew, particularly when operating robotic arms. Requirements are to accomplish this through specifying techniques such as matching of crew and robot frames of reference or, at minimum, providing appropriate frame-of-reference labels and visual cues.]

10.7 Information Management

10.7.1 Information Management Capabilities – Provision

[V2 10113] The information management system **shall** provide data critical to mission planning, mission operations, system maintenance, and system health and status at an appropriate level of detail to support effective and efficient crew performance.

[Rationale: The information management system is to provide all types of data needed by the crew to perform their tasks at the proper level of detail needed for each task in such a way that it is rapidly recognized and understood. The system should minimize requirements for making mental calculations or transformations and use of recall memory. Task analysis can help define data and level of detail needed for crew task performance.]

10.7.2 Alerts

10.7.2.1 Visual and Audio Annunciations

[V2 10114] The information management system **shall** provide visual and audio annunciations to the crew for emergency, warning, and caution events.

[Rationale: Visual and audio annunciations are to be defined and provided for all levels of alerts. Annunciations are to have dual coding, e.g., be seen and heard, and are to be distinctive

and identifiable. Audio annunciations can implement speech alarms as a way to provide information efficiently and lead to quick and accurate response times.]

10.7.2.2 Automatic Set-Point Alerts

[V2 10115] The system **shall** alert the crew if the selected set-points are outside safe limits.

[Rationale: A set-point is the target value that an automatic control system aims to reach. Two set-points, e.g., high and low set-points, define a range of values within which a system operates. The crew or ground personnel may be able to select set-points in an automatic control system. In the event that a set-point is changed to one that is outside the safe limit, the system will alert the crew that a change has been made that puts the set-point at an unsafe setting. The alert acts as a check to ensure that the crew intentionally made the change and reminds them that there is a hazard associated with a set-point in this range.]

10.7.2.3 Audio Annunciation Silencing

[V2 10116] The information management system **shall** provide a manual silencing feature for active audio annunciations.

[Rationale: The capability to manually silence any alarm is to be provided to the crew. Requirements are to prescribe a method of manual silencing that is intuitive, achievable from different locations within the cabin and during different flight phases, and consistent with any other manual silencing mechanisms.]

10.7.2.4 Visual and Auditory Annunciation Failures

[V2 10117] The information management system **shall** test for a failure of the visual and auditory annunciators upon crew request.

[Rationale: A mechanism is to be provided to allow the crew to independently test for a failure of the visual or auditory annunciation system. The mechanism is to consist of a control to initiate the test and some type of display to provide the results for the visual and auditory portions of the system.]

10.7.2.5 Visual Alerts - Red

[V2 10118] The color red **shall** be used as a visual indicator for the highest alert level.

[Rationale: In situations where there is a need to communicate information about the highest level of alert, the color red is to be used for the text and/or graphics.]

10.7.2.6 Visual Alerts - Yellow

[V2 10119] The color yellow **shall** be used as a visual indicator for the second highest alert level.

[Rationale: In situations where there is a need to communicate information about the second highest level of alert, the color yellow is to be used for the text and/or graphics.]

10.7.3 Information Management Capabilities

10.7.3.1 Information Management Methods and Tools

[V2 10120] The information management system **shall** provide methods and tools that allow the crew to effectively input, store, receive, display, process, distribute, update, and dispose of mission data.

[Rationale: The system is to provide the hardware and software architecture, including crew interfaces necessary, to manage all of the data in the information management system. Usability testing can help ensure that the information management methods and tools provided are easy to use and effective.]

10.7.3.2 Information Management Standard Nomenclature

[V2 10121] The information management system **shall** use standard nomenclature.

[Rationale: Nomenclature throughout the information management system is to follow program standards or, at minimum, is consistent throughout the system. Standard nomenclature is most often ensured through specific program operations nomenclature standards.]

10.7.3.3 Information Management Compatibility

[V2 10122] The information management system **shall** be compatible with other systems within the spacecraft.

[Rationale: The information management system displays, controls, nomenclature, and user interfaces are to be consistent and compatible with other systems within the spacecraft. Requirements are to ensure that the systems work together successfully and efficiently to ensure task and mission success.]

10.7.3.4 Information Management Operation Rate

[V2 10123] The information management system **shall** operate at a rate that enables the crew to perform tasks effectively and efficiently, e.g., within acceptable error limits and scheduled operating times.

[Rationale: Response times that are too long prevent the crew from performing tasks effectively and efficiently; thus, minimal system response times are to be established for information management functions.]

10.7.3.5 Information Management Data Provision

[V2 10124] The information management system **shall** provide the crew with data to perform tasks at each workstation where those tasks are to be performed.

[Rationale: Design requirements are to specify which tasks are to be performed at which workstations and subsequently ensure that all task-relevant data be available at those workstations. Task analysis is to be performed to identify tasks and data needs.]

10.7.3.6 Information Management Security

[V2 10125] The information management system **shall** have features for the protection of sensitive and private data, transmission, secure viewing, and sender verification.

[Rationale: Data sensitivity and protection or handling measures are to be identified such that mechanisms for the protection of the data such as encryption or password protection can be put in place.]

10.7.3.7 Information Management Ground Access

[V2 10126] The information management system **shall** allow for ground access to perform all onboard database functions without crew intervention.

[Rationale: Ground personnel are to have the capability to access and perform data management functions for all onboard data. Architecture is to be in place to support this as a ground-to-vehicle interaction, without crew participation. This access is to take the following into consideration: data protection, data transmission bandwidth, and—most importantly—visibility to the crew. Although the crew is not required to accomplish these ground-initiated functions, the crew is to be aware that the operations will occur, are presently occurring, or have taken place.]

10.7.3.8 Information Capture and Transfer

[V2 10127] The information management system **shall** provide a capability for the crew to capture and transfer information in a portable fashion.

[Rationale: The system is to provide the crew with the capability to transport information from a display to another location. Requirements are to specify techniques such as screenshots or digital downloads or captures to provide access to displayed information in locations where there is no permanent display device.]

10.7.3.9 Information Annotation

[V2 10128] The information management system **shall** provide a capability for annotation by the crew.

[Rationale: The capability to allow the crew to annotate data displays through techniques such as real-time markup capability, direct display modification, or hardcopy printing and redlining is to be provided by the system. Annotation capability provides documentation of changes to procedures or notes and tips from the crew that may be forgotten if left only as verbal commentary.]

10.7.3.10 Information Backup and Restoration

[V2 10129] The information management system **shall** provide for crew-initiated data backup and restoration for all mission data and automatic backup for critical data.

[Rationale: Measures such as data backups and data restores are to be in place to ensure that data are protected from accidental loss. Backups are to occur automatically for critical data that cannot be recreated; backups for less critical data are to be initiated on crew request, using standard user interface commands.]

10.7.3.11 Alternative Information Sources

[V2 10130] The information management system **shall** provide alternative information sources for use in the event of the loss of the information management system.

[Rationale: In the event that the information management system becomes unavailable, the system needs to ensure that backup information sources are available for critical tasks, e.g., emergency procedures may have paper cue cards.]

10.7.3.12 Software System Recovery

[V2 10131] The information management system **shall** be rapidly recoverable from a software system crash.

[Rationale: In the event of a system failure, the information management software is to be sophisticated enough to be rapidly recovered. Additionally, the minimum time delay that is acceptable before the information management system becomes operational after a system crash is to be identified.]

11. SPACESUITS

Section 11 includes requirements that are specific to spacesuits and suited operations. Spacesuits provide a self-contained habitable atmosphere that sustains human life and meets crew health, safety, and performance needs throughout suited mission durations. Suited activities (EVA, LEA or IVA) are an essential part of many human space missions. Unless otherwise identified as being applicable to EVA, IVA or LEA spacesuits, requirements in this section will be considered applicable to both. For the purposes of this NASA Technical Standard, the following definitions are used for LEA Spacesuit Systems and EVA Spacesuit Systems:

LEA Spacesuit System Definition: Any spacesuit system designed without an independent life support system and primarily for use during launch, entry, and abort phases of space flight, primarily to protect against toxic exposure, ebullism, hypoxia, and decompression sickness in the event of an unplanned cabin depressurization or toxic release into the cabin. It may also be worn during other dynamic phases of flight such as rendezvous and docking during which there is an increased risk of cabin depressurization due to cabin leaks. The duration for which LEA spacesuits are designed to operate will depend on mission scenarios and may range from a few hours to several days per use.

EVA Spacesuit System Definition: Any spacesuit system designed to allow astronauts to perform tasks outside of a spacecraft or habitat in microgravity or partial gravity. Performance of space flight EVA consists of placing a human in a micro-environment that provides all the life support, nutrition, hydration, waste, and consumables management function of an actual space vehicle, while allowing crewmembers to perform mission tasks. EVA spacesuits are designed to be used for durations of less than a day due to potential human and suit system constraints. This includes all suited phases (e.g., prebreathe, leak checks, airlock/cabin/suitport depress).

As described in section 3.1 and Appendix E, many other requirements in this NASA Technical Standard are also intended to be applicable to spacesuits; section 11 is a subset of requirements that are uniquely applicable to spacesuits and suited operations. For planetary exploration missions, crew access to the planetary surface within an EVA suit is fundamental to mission success and safety. Suited activities allow many aspects of mission science, exploration, and maintenance. Compliance with the requirements stated here is crucial to the health, safety, and performance of the suited crew. Consult NASA-STD-3001, Volume 1, for EVA health and medical requirements. Consult EVA-EXP-0035, Exploration EVA System Compatibility, for detailed guidance and constraints primarily concerned with safety, design of EVA support equipment, layout of EVA translation paths, and human-machine interfaces for crew operation. It is important for vehicle designers to understand and account for the interfaces between vehicle systems and spacesuits. Human system requirements that require consideration of the suit-to-system interface are also identified in Appendix E.

11.1 Suit Design and Operations

11.1.1 Suited Donning and Doffing

[V2 11001] The system **shall** accommodate efficient and effective donning and doffing of spacesuits for both nominal and contingency operations.

[Rationale: Spacesuit donning and doffing is a non-productive activity. Plus, tedious and difficult tasks are more prone to neglect and human error. Finally, rapid donning can be critical in an emergency. System developers need to consider total system design and human accommodation, including emergency scenarios, assess donning task times, and evaluate features such as unassisted donning.]

11.1.2 Suit Environment

11.1.2.1 Suit Pressure Set-Points

[V2 11006] The suit **shall** provide the capability for the crewmember to select discrete suit pressure set-points within the suit operating pressure ranges during pressurized and unpressurized suited operations.

[Rationale: To implement operational concepts possible in a variable pressure suit, the crewmember is to be able to select the desired discrete pressure setting.]

11.1.2.2 Suit Equilibrium Pressure

[V2 11007] Suits **shall** maintain pressure within 1.72 kPa (0.25 psi) after the suit has achieved an equilibrium pressure for a set-point.

[Rationale: Maintaining a constant pressure level after a set-point has been reached is important to protect the crewmember from discomfort in body cavities and sinuses, especially in the ear. Maintaining a constant pressure level is intended to protect the crewmember in the pressurized suit. Because of the relatively small total pressure volume in the suit, it is important that the pressurized-suited crewmember is exposed to a pressure set-point that is constant (unchanging). Excess fluctuations in suit pressure cause pressurized-suited crewmembers to constantly re-equilibrate pressure in body cavities and sinuses, which increases the likelihood of pressure-induced discomfort in these areas.]

11.1.2.3 Continuous Noise in Spacesuits

[V2 11009] Suits **shall** limit suit-induced continuous noise exposure at the ear to NC-50 or below without the use of auxiliary hearing protection.

[Rationale: This requirement limits noise levels within the suit to allow for adequate voice communications and comfort. This requirement does not apply to alarms, communications, or to any noise experienced during maintenance activities. The noise attenuation effectiveness of hearing protection or communications headsets may not be used to satisfy this requirement unless they are included in the nominal suit configuration, i.e., not added to meet this requirement. Consideration is to be given to protect the frequencies necessary for communications transmission from ambient or suit-generated noise.]

11.1.2.4 EVA Suit Radiation Monitoring

[V2 11010] The suit **shall** provide or accommodate radiation monitoring and alerting functions to allow the crew to take appropriate actions.

[Rationale: Radiation monitors are to provide primary data for controlling crewmember radiation exposures during EVA. The current exposure limits for deterministic effects (short-term

exposure limits) are specified in NASA–STD-3001, Volume 1; and to demonstrate compliance, radiation monitoring is required.]

11.1.2.5 Suited Crewmember Heat Storage

[V2 11011] The system **shall** prevent the energy stored by each crewmember during nominal suited operations from exceeding the limits defined by the range 3.0 kJ/kg (1.3 Btu/lb) > ΔQ stored > -1.9 kJ/kg (-0.8 Btu/lb), where ΔQ stored is calculated using the 41 Node Man or Wissler model.

[Rationale: This requirement applies to nominal microgravity EVA operations and nominal surface EVA operations. Excess heat load and accumulation may quickly reach human tolerance limits and may impair performance and health. Impairment begins when skin temperature increases greater than 1.4ºC (2.5ºF -17) (0.6ºC [1ºF -17.4]) core or if pulse is greater than 140 bpm). Increases in body core temperature may lead to associated performance decrements. Keeping the heat storage value below the performance impairment line allows the crewmember the ability to conduct complex tasks without heat-induced degradation. If the crewmember is in a suit, the heat load may increase rapidly. Supporting data from military aircrew protective ensembles suggest body temperature may increase more rapidly over time in suited crewmembers compared to those in a shirt-sleeve environment. The current change in heat storage limit is to allow nominal suited operations with crewmember metabolic rates of 528 to 2220 kJ/hr (500 to 2100 Btu/hr) without undue heat discomfort.]

11.1.3 Suit Waste Management

11.1.3.1 Suited Body Waste Management – Provision

[V2 11013] Suits **shall** provide for management of urine, feces, menses, and vomitus of suited crewmembers.

[Rationale: The total system is to be designed for body waste collection, as well as disposal of waste in the system's waste management system and cleaning of the suit for reuse. Waste management items are to be able to contain and dispose of human waste with as much containment and isolation as possible. Provisions are to be available for personal hygiene and suit cleaning.]

11.1.3.2 EVA Suit Urine Collection

[V2 11028] EVA suits **shall** be capable of collecting a total urine volume of $V_u = 0.5 + 2.24t/24$ *L*, where *t* is suited duration in hours.

[Rationale: This EVA suit requirement is separate from the LEA suit requirement below requirement [V2 11014] LEA Suit Urine Collection, to ensure that the increased EVA suit hydration (per requirement [V2 11030] EVA Suited Hydration, specifying an additional 8.1 fl oz ≈ 240 mL per hour for EVA suited operations) is a design consideration for EVA suit urine

collection. This straightforward input-output equation does not consider variables such as metabolic rate, relative humidity, or hydration, which could affect the total volume. The voided urine is to be isolated to prevent inadvertent discharge in the suit that could result in injury to a crewmember's skin or mucous membranes or damage to the suit system.]

11.1.3.3 LEA Suit Urine Collection

[V2 11014] LEA suits **shall** be capable of collecting a total urine volume of $V_u = 0.5 + 2t/24$ L throughout suited operations, where t is suited duration in hours.

[Rationale: This requirement allows crewmembers to eliminate liquid waste at their discretion without affecting work efficiency during suited operations. The suit is only responsible for the expected urinary output during the time that the crewmember is in the suit. The urinary collection system is to be capable of collecting all of the crewmember's output in succession, with an average void varying from 100 to 500 mL (3.4 to 16.9 fl oz). The rate of urinary delivery into the system from the body varies by sex (greater for females because of lower urethral resistance) but averages 10 to 35 mL/s (0.34 to 1.2 fl oz/s). Maximum flow rate with abdominal straining in a female may be as high as 50 mL/s (1.9 fl oz/s) for a few seconds. Output collection capacity is designed to match water input potential; the Vu equation does not consider variables such as metabolic rate, relative humidity, or hydration, which could affect total urine volume. The voided urine is to be isolated to prevent inadvertent discharge in the cabin that could result in injury to a crewmember's skin or mucous membranes or damage to equipment.]

11.1.3.4 Suit Urine Collection per Day – Contingency

[V2 11015] For contingency suited operations lasting longer than 24 hours, suits **shall** be capable of collecting and containing 1 L (33.8 fl oz) of urine per crewmember per day.

[Rationale: Urine output may be slightly greater or lower in various phases of the mission associated with g-transitions and fluid intake levels. Rarely, a single void might be as much as 1 L (33.8 fl oz), so the equipment is to be able to accommodate this maximum. Also, in the event of an unrecoverable vehicle pressure failure wherein an extended stay in the suit is used to maintain life, crewmembers are to have the capability to access fecal and urine collection systems. The voided urine is to be contained by the stowage and disposal hardware to prevent inadvertent discharge into the suit that could result in injury to the crewmember's mucous membranes or equipment.]

11.1.3.5 Suit Feces Collection per Day – Contingency

[V2 11016] During contingency suited operations, suits **shall** be capable of collecting 75 g (0.17 lb) (by mass) and 75 mL (2.5 fl oz) (by volume) of fecal matter per crewmember per day.

[Rationale: In the event of an unrecoverable vehicle pressure failure wherein an extended stay in the suit is used to maintain life, crewmembers are to have the capability to access fecal and urine collection systems. Fecal waste collection is to be performed in a manner that minimizes

escape of fecal contents into the general suit environment during microgravity operations because of the high content of possibly pathogenic bacteria contained in the stool. In addition, there is the potential of injury to crewmembers and hardware that could result from such dissemination. EVA suits are to accommodate for fecal waste collection and containment during all suited activities. Suited activities are nominally not expected to exceed 10 hours. The waste quantities reflect the altered composition of the nutrition supplied during contingency suited operations and are characteristically low in residue.]

11.1.3.6 Suit Isolation of Vomitus

[V2 11017] Suits **shall** be shown to not create any catastrophic hazards in the event of vomitus from the crewmember.

[Rationale: SAS has affected crewmembers in the first 72 hours of flight. The crew is nominally suited during the first 72 hours of flight for certain dynamic phases; vomiting in the suit may occur at these times or if a contingency EVA occurs within that timeframe. On the planetary surface, a high magnitude SPE could result in exposures that produce prodromal nausea and vomiting. If vomitus enters the internal suit environment, it should be kept away from the suited crewmember's naso-pharyngeal space. Uncontrolled accumulation of vomitus may also interfere with a crewmember's vision.]

11.1.4 Suit Vision

11.1.4.1 Suited Field of Regard

[V2 11018] Suits **shall** provide a field of regard sufficient to allow the crewmember to accomplish required suited tasks.

[Rationale: To enhance work efficiency index and mission success, the visor is to have minimal interference with nominal visual acuity. The visor is to promote an adequate field of regard to perform ground, IVA, and EVA tasks and prevent tunnel vision. Suit designers need to consult with vehicle designers.]

11.1.4.2 Suit Helmet Optical Quality

[V2 11019] Suit helmets **shall** have sufficient optical qualities to allow the crewmember to accomplish required suited tasks and maintain a level of SA necessary to maintain safety.

[Rationale: To enhance work efficiency index and mission success, the visor is to have minimal interference with nominal visual acuity. The visor is to minimize haze, discoloration, and fog.]

11.1.4.3 Suit Helmet Luminance Shielding

[V2 11020] Suit helmets **shall** provide protection to suited crewmembers from viewing objects with luminance that could prevent successful completion of required suited tasks.

[Rationale: Individual tasks or crewmembers may require or desire higher or lower lighting levels than that provided for other tasks or crewmembers.]

11.1.4.4 Suit Helmet Visual Distortions

[V2 11021] Suit helmets **shall** be free from visual distortion.

[Rationale: To enhance mission success, vision through a suited crewmember's helmet is to be free of visual distortion.]

11.1.4.5 Suit Helmet Displays

[V2 11022] Suit helmet field of regard **shall** be unencumbered if helmet- or head-mounted displays are provided.

[Rationale: To enhance mission success, vision through a suited crewmember's helmet is to have minimal interference with nominal visual acuity. Inclusion of any display in the helmet is to promote an adequate field of regard to perform ground, IVA, and EVA tasks and prevent tunnel vision.]

11.1.5 Suit Information Management

[V2 11023] The system **shall** allow the crewmember to effectively input, store, receive, display, process, distribute, update, monitor and dispose of relevant information on consumable levels, suit status and alerts, and biomedical data.

[Rationale: Feedback of relevant suit atmospheric and physiologic information to the crew allows better consumable management, improves optimization of EVA task performance, and reduces risk of physiologic stress/injury. Having insight into trends in physiological parameters and life-sustaining consumables allows the IVA or EVA crew to act prospectively in preventing unsafe operating conditions or responding to off-nominal scenarios. This requirement may be met by integrated systems with the details of each system's responsibility defined in individual System Requirements Documents (SRDs) and in Information Requirements Documents (IRDs). Where feasible, it may be desirable for ground medical support to see biomedical telemetry during contingency and mission-preserving EVA, as well as during unrecoverable vehicle pressure loss, to ensure the health and safety of the crew. These data will also be monitored during nominal lunar surface operations to ensure the health and safety of the crew, although automated suit algorithms may be the primary method rather than ground medical support. Derived body core temperature and heart rhythm (real-time) are desired for microgravity operations, and derived body core temperature is desired for lunar operations. Note that crew may refer to the suited crewmember, the intravehicular crew, or ground crew. The recipients of the data should be defined by the program or project. Relevant information should be determined through task analysis.]

11.1.6 Pressure Suits for Protection from Cabin Depressurization

[V2 11100] The system **shall** provide the capability for crewmembers to wear pressure suits for sufficient duration during launch, entry, descent (to/from Earth, or other celestial body) and any operation deemed high risk for loss of crew life due to loss of cabin pressurization (such as in mission dockings, operations during periods of high incidence of Micrometeoroids and Orbital Debris (MMOD) or complex vehicle maneuvers).

[Rationale: Pressure suits for each crewmember are required to protect the crew in the event of a large cabin leak beyond the vehicle's ability to feed and maintain a habitable atmosphere for an operationally relevant period of time. The duration the vehicle/suit system must maintain habitability during exploration class missions may be orders of magnitude longer than during LEO operations, where emergency return to Earth can be measured in hours. The use of pressure suits increases the probability of crew survival by allowing crewmembers sufficient time to remedy any vehicle failure and arrive at the next closest breathable atmosphere, either on Earth or alternative safe haven.

Launch, entry, and descent operations have the increased probability of decompression events based on past space flight history. Docking event risk profile is dependent on vehicle size, docking vestibules, and availability of access to alternate sealable pressurized volumes. For operations within the spacesuit, the crew will be protected against ebullis, hypoxia, toxic exposure and decompression sickness. Refer to the Chapter 11 for requirements (such as required O_2 and CO_2 concentrations, DCS prevention, suit pressures, waste management, etc.) associated with the design and capabilities of a pressure suit.

Note: Alternate methods of providing equivalent protection against decompression events should be evaluated for each operational scenario. Also, reference [V2 9053] Protective Equipment for applicability.]

11.2 Suited Functions

11.2.1 Ability to Work in Suits

[V2 11024] Suits **shall** provide mobility, dexterity, and tactility to enable the crewmember to accomplish suited tasks within acceptable physical workload and fatigue limits while minimizing the risk of injury.

[Rationale: Suited crewmembers are to be able to perform tasks required to meet mission goals and operate human-system interfaces required for use during suited operations. Suits can limit the crew mobility, dexterity, and tactility below that of unsuited crewmember. Wear and tear on the suit as exposed to extraterrestrial environments should be considered. Suit pressurization can further reduce crewmember capabilities. For example, the crewmember should not have to remove gloves to operate the controls while in the LEA suit. In the event of a rapid decompression event, the crewmember will not likely have enough time to don any unsecured equipment.]

11.2.2 Suited Nutrition

[V2 11025] The system **shall** provide a means for crewmember nutrition in pressure suits designed for surface (e.g., Moon or Mars) EVAs of more than 4 hours in duration or any suited activities greater than 12 hours in duration.

[Rationale: Additional nutrients, including fluids, are necessary during suited operations as crewmember energy expenditure is greater during those activities. Additional kilocalories (kcal), based on metabolic energy replacement requirements from moderate to heavy EVA tasks, allow the crewmember to maintain lean body weight during the course of the mission. Lean body (especially muscular) weight maintenance is a key component of preserving crew health during the missions and keeping performance at a level required to complete mission objectives. Nutritional supply during suited operations allows the crewmembers to maintain high performance levels throughout the duration of the EVA. Apollo astronauts strongly recommended the availability of a high-energy substance, either liquid or solid, for consumption during a surface EVA as mentioned in the Apollo Medical Summit. During contingency microgravity EVAs and/or for EVAs less than 4 hours in duration, this capability is not required. During long-duration suited operations such as an unplanned pressure reduction scenario, the crew is to be able to consume nutrition from an external source to maintain crew performance.]

11.2.3 Drinking Water

11.2.3.1 LEA Suited Hydration

[V2 11029] The system **shall** provide a means for on-demand crewmember hydration while suited, including a minimum quantity of potable water of 2 L (67.6 fl oz) per 24 hours for the LEA suit.

[Rationale: Potable water is necessary during suited operations to prevent dehydration caused by perspiration and insensible water loss, as well as to improve crewmember comfort. LEA-suited hydration has to be available both while suited and unpressurized as well as suited and pressurized. Having the potable water system be rechargeable from an external source is acceptable as long as the suit system has sufficient capacity to allow on-demand ready access to water at crewmember discretion without impacting work efficiency. During long-duration LEA-suited operations such as an unplanned pressure reduction scenario, the crew is to be able to consume water from an external source to prevent crew performance degradation associated with dehydration.]

11.2.3.2 EVA Suited Hydration

[V2 11030] The system **shall** provide a means for on-demand crewmember hydration while suited, including a minimum quantity of potable water of 240 mL (8.1 fl oz) per hour for EVA suited operations.

[Rationale: Potable water is necessary during suited operations to prevent dehydration caused by perspiration and insensible water loss, as well as to improve crew comfort. Having the potable water system be rechargeable from an external source is acceptable as long as the internal suit reservoir has sufficient capacity to allow ready access to water without impacting work efficiency. Hundreds of microgravity EVAs have been performed using a 950 mL (32.1 fl oz) in-suit drink bag, but this alone does not meet the minimum recommendations for hydration during moderate activity. Factors that may affect an individual's hydration needs include body size, sweat rates, thermal environment, humidity, and metabolic rate. Given the wide range of differences between people and EVA characteristics, 240 mL (8.1 fl oz)/hour is the minimum recommendation to cover most applications. During surface EVAs, crewmembers will most likely be suited for 10 hours, including approximately 7 hours expending energy on the lunar surface. Apollo astronauts strongly recommended the availability of an appropriate quantity of water for consumption during a lunar EVA. Specifically, Apollo astronauts recommended during the Apollo Medical Summit, that the availability of 240 mL (8.1 fl oz) per hour of water for consumption during a lunar EVA, with water available for contingency scenarios such as a 10-km walk-back in case of rover failure. The intent of this requirement is for the suit system to have sufficient capacity to allow on-demand ready access to water at crew-discretion without impacting work efficiency.]

11.2.4 Suited Medication Administration

[V2 11027] The system **shall** provide a means for administration of medication to a suited, pressurized crewmember for pressurized suited exposures greater than 12 hours.

[Rationale: As a contingency, administration of medication from an external source to a suited crewmember may be required at a time in which it is not possible to doff the suit, e.g., during an unplanned pressure reduction scenario. Medication and administration method designs are to be integrated into suit design.]

11.2.5 Suited Relative Humidity

[V2 11031] For suited operations, the system **shall** limit RH to the levels in Table 34, Average Relative Humidity Exposure Limits for Suited Operations.

[Rationale: Average humidity is to be maintained above the lower limits stated to ensure that the environment is not too dry for the nominal functioning of mucous membranes. During low humidity exposures, additional water is to be provided to the crew to prevent dehydration. Humidity is to be maintained below the upper limits for crew comfort to allow for effective evaporation and to limit the formation of condensation. Excess moisture in the glove can contribute to trauma at the fingertips.]

Table 34 — Average Relative Humidity Exposure Limits for Suited Operations

Average RH	Time Allowed
RH ≤ 5%	1 hr
5% < RH ≤ 15%	2 hr
15% < RH ≤ 25%	8 hr
25% < RH ≤ 75% (nominal range[1])	Indefinite[2]
1. Nominal humidity range is included for completeness. 2. Assumes temperature is within nominal range in accordance with requirement Comfort Zone [V2 6012] in this NASA Technical Standard.	

11.2.6 LEA Suited Decompression Sickness Prevention Capability

[V2 11032] LEA spacesuits **shall** be capable of operating at sufficient pressure to protect against Type II decompression sickness in the event of a cabin depressurization.

[Rationale: LEA spacesuits are worn inside spacecraft to protect crewmembers in the event of contingencies such as contamination or depressurization of the spacecraft cabin. For example, in Soyuz 11, a rapid decompression due to a faulty valve occurred at an altitude of about 104 miles, led to the death of all three (unsuited) crewmembers within two minutes. Protection against serious life-threatening (Type II) DCS in the event of an unplanned rapid cabin depressurization depends on providing adequate suit pressure to crewmembers because there is no opportunity for oxygen prebreathe or immediate post event treatment. Based on best available data and computational models, LEA spacesuit pressure of 40 kPa (5.8 psia) will limit the probability of Type II DCS occurrence to less than 15% for a rapid depressurization when saturated at a cabin pressure of 14.7 psia. If cabin pressure is nominally less than 14.7 psia, as expected during Exploration missions, the resulting minimum suit pressure could be less than 5.8 psia.]

11.3 Suited Atmosphere

11.3.1 Suited Thermal Control

[V2 11033] The suit **shall** allow the suited crewmembers and remote operators to adjust the suit thermal control system.

[Rationale: The ability to control suited atmospheric conditions is important for crew health and comfort, and for mission tasks, to ensure efficient and effective performance. Temperature can be adjusted in a number of ways depending on the suit and vehicle system design (e.g., changing water flow, inlet temperature.]

11.3.2 Suited Atmospheric Data Recording

[V2 11034] Systems **shall** automatically record suit pressure, ppO_2, and $ppCO_2$.

[Rationale: Access to atmospheric data is needed for suit systems, as each of these parameters is critical to crew health and comfort. Additionally, the ability to view past recorded data helps to prevent suited environmental conditions that could harm the crew or suit system and can aid in the effort to troubleshoot problems. ppO_2 can be directly measured or calculated indirectly and recorded. Recording of thermal comfort variables may be useful.]

11.3.3 Suited Atmospheric Data Displaying

[V2 11035] Suits **shall** display suit pressure, ppO_2, and $ppCO_2$ data to the suited crewmember.

[Rationale: These atmospheric parameters are critical to human health and comfort, and access to this atmospheric data needs to be provided to the crewmember. The crewmember needs to view the environmental status in real time to help prevent environmental conditions that could harm them or the suit system. The implementation of the display is addressed by various requirements in section 10 of this NASA Technical Standard.]

11.3.4 Suited Atmospheric Monitoring and Alerting

[V2 11036] Suits **shall** monitor suit pressure, ppO_2, and $ppCO_2$ and alert the crewmember when they are outside safe limits.

[Rationale: Systems are to be capable of monitoring the atmosphere to identify when parameters are outside set limits so that the system can alert the crew and the crew can take appropriate actions to maintain health and safety. See sections 10.3.4, Audio Displays, and 10.7.2, Caution and Warning, in this NASA Technical Standard for additional information. Note that crew may refer to the suited crewmember, the intravehicular crew, or ground crew. The recipients of the data should be defined by the program or project. Monitoring and alerting of thermal comfort variables may be useful.]

11.3.5 Nominal Spacesuit Carbon Dioxide Levels

[V2 11039] The spacesuit **shall** limit the inspired CO_2 partial pressure (P_ICO_2) in accordance with Table 35, Spacesuit Inspired Partial Pressure of CO_2 (P_ICO_2) Limits.

[Rationale: Spacesuit design (flow rate, helmet shape, etc.) and crewmember metabolic rates (average and transient) affect the extent to which CO2 accumulates inside a spacesuit and is inspired by crewmembers. Inspired CO_2 partial pressure levels in Table 35 are based on review of scientific literature combined with past EVA experience, prescribed standardized human-in-the-loop testing, suit inlet CO_2 of <2 mmHg, and suit ventilation utilized in heritage designs. Verification methods would utilize the standardized testing method as published in ICES-2018-15, Bekdash, et al., July 2018.]

Note: Off-nominal CO_2 values are not included within this NASA Technical Standard due to the unique circumstances of each mission (expected human performance, duration of exposure, *access to medical care, etc.) and would be derived as a lower level program/project requirement.*

Table 35—Spacesuit Inspired Partial Pressure of CO_2 (P_ICO_2) Limits †

P_ICO_2 (mmHg)	Allowable Cumulative Duration (hours per day)
$P_ICO_2 > 15.0$	Do Not Exceed
$12.5 < P_ICO_2 \le 15.0$	≤ 0.5
$10.0 < P_ICO_2 \le 12.5$	≤ 1.0
$7.0 < P_ICO_2 \le 10.0$	≤ 2.5
$4.0 < P_ICO_2 \le 7.0$	≤ 7.0
$P_ICO_2 \le 4.0$	indefinite

The requirements in Table 35 are to be met in the presence of the expected average and transient metabolic rates for the full suited duration, including prebreathe, checkout, EVA, and repressurization time. Total duration in the suit is not to exceed 14 hours.

† The values in Table 35 are based on Shuttle and ISS EVA experience, representing a frequency of up to 4 EVAs over a 14-day mission or up to 5 EVAs during a 6-month mission. If additional frequency of EVAs beyond the existing experience base is required, monitoring of crewmembers for hypercapnic signs and symptoms will be necessary until a sufficient experience base is generated.

11.4 Suited Metabolic Rate

11.4.1 EVA Suited Metabolic Rate Measurement

[V2 11037] The system **shall** measure or calculate metabolic rates of suited EVA crewmembers.

[Rationale: Real-time monitoring during EVA is a current medical requirement and provides awareness of exertion level, including whether or not exertion levels are above or below normal for a particular crewmember and task.]

11.4.2 EVA Suited Metabolic Rate Display

[V2 11038] The system **shall** display metabolic data of suited EVA crewmembers to the crew.

[Rationale: Metabolic data are important indicators of human health and performance, and access to these data needs to be provided to the crew. The crew needs to view the metabolic information in real time to provide awareness and potential adjustment of exertion level, including whether or not exertion levels are above or below normal for a particular crewmember and task. Note that crew may refer to the suited crewmember, the intravehicular crew, or ground crew. The recipients of the data should be defined by the program or project.]

11.5 Incapacitated Crew Rescue (ICR)

[V2 11101] Resources **shall** be provided to rescue an incapacitated suited crewmember(s).

[Rationale: Incapacitation of a suited crewmember can occur in microgravity or on planetary surfaces. An incapacitation event could render the affected crewmember partially or fully reliant on the rescuer crewmember either temporarily or continually during the ICR. Resources needed during an ICR include appropriate hardware aids (restraints, translational aids, lifting handles, hoisting devices, etc.), consumables, and operational planning for both the incapacitated crewmember and rescue crewmember for all ICR phases. ICR phases encompass the initial occurrence of the event through medical stabilization of the incapacitated crewmember inside the vehicle (including suit doffing).]

12. GROUND ASSEMBLY DESIGN AND EMERGENCY EGRESS OPERATIONS

This section focuses on the design of space flight systems, hardware, and equipment that are accessed, used, or interfaced in some way by personnel other than the space flight crews (e.g., ground support personnel) during preflight ground processing, launch, landing, recovery, contingency, and ground emergency egress operations.

12.1 Ground Assembly Design

This section focuses on the design of space flight systems, hardware, and equipment that are accessed, used, or interfaced in some way by personnel other than just the space flight crews (e.g., ground support personnel). Space flight systems include those systems that support crew launch, orbit, transit, surface ops, return, and recovery. Ground support personnel perform numerous tasks utilizing space flight systems, hardware, and equipment at times other than during space flight such as during ground operations before launches and after landings. Incapable, incomplete, or improper performance of tasks and/or improper use of hardware and equipment by the ground support personnel could lead to LOM or LOC of the space flight crew.

The requirements in this section ensure that the capabilities and needs of the ground processing crew are considered during the design and development of the flight system along with ensuring that the flight system is not compromised during the assembly, test, and operational phases.

The requirements listed in section 12.1 of this NASA Technical Standard apply only to the design and development of flight systems interfaced by ground support personnel at integration, launch, landing, recovery, and deservicing sites. These requirements are optional for designs at manufacturing and development sites.

This section is applicable for the following: when NASA is performing the ground processing for vehicles built by non-NASA vendor or when one vendor builds the vehicle and a second vendor is *responsible for the assembly, integration, and maintenance. If one vendor is responsible for the design, assembly and maintenance then this section does not apply.*

12.1.1 System Assumptions

[V2 12003] Each human space flight program **shall** document the system support design and environment:

a. Work environment (e.g., lighting, heating, atmosphere, gravity).

b. Tools and support equipment.

c. Ground support personnel characteristics (e.g., size, training, experience, number, physical and cognitive capabilities, skills, ergonomics).

d. Ground support personnel tasks (e.g. environment, complexity, scheduling).

[Rationale: A separate support system (i.e., facilities, equipment, personnel, procedures) is required to support the space flight system. The two systems have to work together so that the space flight system can achieve its performance goals. The space flight system developer may not be in control of the support system; but to properly design the space flight system, the developer has to have a clear understanding of the support system, including its functions and users.]

12.1.2 Ground Support Personnel Accommodation

12.1.2.1 Anthropometry, Biomechanics, Range of Motion, and Strength

[V2 12004] Each program **shall** identify an anthropometry, biomechanics, range of motion, and strength data set for the ground support population to be accommodated in support of all requirements in this section of this NASA Technical Standard.

[Rationale: Ground support personnel anthropometry, reach, biomechanics, range of motion, and strength need to be defined for the program in a data set. Ground support personnel data sets may represent different populations than space flight crew. Existing data sets found in the HIDH can be used; but if not, applicable new data sets may need to be developed. Systems need to accommodate the physical capabilities and limitations of ground support personnel to allow for required servicing, maintenance, assembly, testing, or operational use by ground support personnel (e.g., rescue, flight test, special docking). Systems architecture and vehicle layout and tasks should not force ground support personnel to move, twist, or stretch into awkward positions. Tasks that require awkward positioning can increase the likelihood of errors or injury.]

12.1.2.2 Protective Equipment

[V2 12005] The system **shall** accommodate ground personnel protective equipment and attire.

[Rationale: The design has to accommodate for ground personnel functions constrained or increased by protective equipment or combinations of such (e.g., pressurized or unpressurized suits, breathing hoses or air packs, gloves, fall protection harnesses, masks, hats or helmets, sensors, cords). Protective equipment often limits human capabilities (e.g., visual envelope, range of motion, reach envelope, audio, communication, grasp) and often increases personnel work volumes or quantity of personnel anticipated (e.g., pressurized suited tasks often require a minimum of two personnel and air packs or hoses). Design factors for audio, communication, displays, and control systems should accommodate for face, ear, and/or hand protection (e.g., larger knobs, increased volume, larger tactile surfaces, resistive touchscreens). Integrated task analysis has to be performed to identify designs or functions that may be affected by protective equipment or attire. Physical characteristics of protective equipment need to be provided to designers so the protective equipment can be accommodated in system design.]

12.1.2.3 Volume Accommodation

[V2 12006] The system **shall** provide the volume necessary for the ground support personnel to perform all ground processing tasks using the required tools and equipment.

[Rationale: The physical work envelopes have to accommodate full or partial access for the expected number of ground support personnel, equipment required to perform the task, and any associated protective equipment. The volume has to accommodate body, work, reach, visual, tool, and protective equipment envelopes to accomplish the task. The physical work envelopes of doors, hatches, and entryways should consider further volumetric restrictions imposed by ground processing, including door/hatch masses and hinges, if captive, actuators, or other entry mechanisms along with air ducts, cords, sensors, protective covers, safety equipment, portable lighting, and potential mechanical assist devices (e.g., personnel and equipment entry platforms, lift devices). For safe passage, timeliness, and to prevent collateral damage, hatches and ingress/egress openings have to be large enough for the ground support personnel to pass safely and efficiently in situations involving suited personnel, transporting equipment or hardware through the opening, emergency or contingency operations, or incapacitated personnel rescue.]

12.1.2.4 Ground Processing – Induced Forces

[V2 12007] Systems, hardware, and equipment **shall** be protected from or be capable of withstanding forces imposed by the ground support personnel or ground support equipment (GSE), in a 1-g environment.

[Rationale: Either by vehicle design (preferred) or through other means (e.g., labels, placard, cover, training, walking platforms, procedures), the space flight system needs to be protected from the forces imposed by ground support personnel (and their associated equipment) while performing vehicle tasks. Furthermore, any accessible items that could be inappropriately used such as handles, steps, handrails, or mobility aids should either be designed to withstand the forces imposed by the ground support personnel or be clearly labeled as a keep-out zone. Historical experience with Shuttle and ISS has shown that it is important to make it clear which

parts of a vehicle may not be used as handles, steps, or handrails so that ground support and space flight crews do not inadvertently damage delicate portions of the vehicle. Priority should be given to areas where ground support and space flight crews will traverse and /or work most frequently and those areas with the most severe potential hazard consequences.]

12.1.2.5 Systems Accessibility

[V2 12008] System components, hardware, and/or equipment that requires ground support personnel inspection or interaction **shall** be accessible.

[Rationale: Ground support personnel have to be able to access system components, hardware, or equipment that requires inspection or interaction. Consideration needs to be given for type of access and inspection (e.g., physical and visual) needed for each component, hardware, and equipment during vehicle design. Proximity and envelope required for the access and inspection is defined by the function.]

12.1.2.6 Tool Clearance

[V2 12009] The system **shall** provide tool clearances for tool installation and actuation for all tool interfaces during ground processing.

[Rationale: The required tool clearance for fit and actuation is to be determined and applied to the design of hardware. Consideration needs to be given to type of tool, the user's hand action, the tool's motion envelope and forces needed, the user population hand anthropometric data, adjacent equipment, the inclusion and use of appropriate shields/guards/gloves, and the need for tool tethering when determining the minimum clearance dimensions.]

12.1.3 Hardware and Software Design to Support Ground Operations

12.1.3.1 Flight Hardware Differentiation

[V2 12010] Flight system components that have the same or similar form but different functions **shall** not be physically interchangeable.

[Rationale: Components requiring installation (including, but not limited to, Line Replacement Units (LRUs) that are not interchangeable functionally will not be interchangeable physically. This requirement addresses installation of a component in the wrong location. While some installable units may be used for the same function in multiple instances (e.g., redundant strings), many may be physically similar but functionally distinct. In such cases, installation in the wrong location could result in damage to the hardware or to the system into which it is inserted. This requirement is intended to preclude such installation in the wrong location. Physical designs may include incompatible bolt patterns, pin/hole alignment, and/or baseplate differences that do not allow incorrect and/or inadvertent location installation. In addition to differentiation, labeling to show distinctions should be applied.]

12.1.3.2 Hardware Protection

[V2 12011] The system **shall** provide a means of protecting flight hardware and equipment from damage during ground processing.

[Rationale: Equipment that can reasonably sustain damage during ground processing should have a means of being protected during ground operations (e.g., window covers, wire covers, propulsion line covers). Note that removable Ground Support Equipment can be used to accomplish this goal.]

12.1.3.3 Mobility Aids

[V2 12012] The system **shall** provide mobility aids to support expected ground support personnel tasks.

[Rationale: Mobility aids such as handholds allow ground support personnel to safely and efficiently move from one location to another, preventing inadvertent damage to equipment. Required tasks will need to be determined by task analysis, which will include the identification of mobility aids.]

12.1.3.4 Equipment Handling Design

[V2 12013] All items designed to be carried, supported, or removed and replaced **shall** have a means for grasping, handling, and carrying.

[Rationale: This requirement is intended to avoid damage to flight hardware and to prevent injury to ground support personnel. Items that are unable to be reasonably moved may incur injury to ground support personnel or damage to the flight systems if handled inappropriately. Flight items that have to be moved may be damaged if handled inappropriately. Damage to flight hardware and injury to the ground support personnel can result from poor grips on a non-handle protrusion or from protrusions that do not hold the weight of the hardware. Non-handle protrusions can break and lead to dropping flight hardware. Handles or handholds need to be designed to support the weight of the hardware, any lifting mechanisms, accommodate bare or gloved hands where appropriate, be non-slip, and/or be clearly labeled.]

12.1.3.5 Inadvertent Operation Prevention

[V2 12014] The system **shall** be designed to prevent inadvertent operation of controls during ground processing.

[Rationale: The system needs to be designed to preclude inadvertent operation. For example, accidental activation by contact can be prevented by the use of guards, covers, and physical separation from other controls. Accidental activation of commands can be prevented with an "arm-fire" mechanism. Two-step commanding allows for ground support personnel confirmation before completing critical, hazardous, or destructive commands. Controls need to

be spaced to prevent inadvertent actuation of adjacent switches. For example, hard plastic, molded covers may be placed over contact-sensitive items, covers placed over adjacent switches, or metal foot and handholds may be added to assure only applicable steps are executed.]

12.1.3.6 Incorrect Installation Prevention

[V2 12015] System hardware and equipment **shall** be designed to prevent incorrect mounting or installation.

[Rationale: This requirement is intended to assure that fasteners are inserted in the correct holes, brackets are attached in the correct location, connectors are installed in the correct position, etc. Improperly mounting equipment during ground processing will result in unsafe conditions for space flight crews and increase the risk of LOC/LOM events through damage to hardware or changes in configuration during launch and ascent. Physical features to prevent incorrect mounting or installation largely prevent these situations. Examples of physical features include supports, guides, size or shape differences, fastener locations, and alignment pins. Physical features are the first line of defense for preventing such errors. In addition to physical features, labeling or marking mitigates human error. Visual indication might include any marking on or adjacent to the hardware/equipment interface, labels, or color coding that provides information about mounting. Unique labeling of hardware/equipment provides an indication that the item to be mounted and the mounting location match. Labels provide contextual information to help assure that the ground support personnel do not attempt to install a hardware item incorrectly; such an attempt could damage the hardware or the interfaces on the vehicle.]

12.1.3.7 Pre-Defined Tool Set

[V2 12016] The system **shall** be designed to be assembled, prepared for launch, maintained, and reconfigured using a pre-defined set of standard tools and lesser set of any pre-established set of specialized tools.

[Rationale: Establishing a minimal set of tools for pre and postmission processing of flight hardware requires integration across space flight systems, hardware, and equipment designs. The goal is to have an integrated set of tools (across systems or programs) that can be used for all ground processing tasks, using common tools wherever possible. Defined toolsets would reduce the number and types of tools and subsequently reduce the number and types of fasteners. Minimizing the variations and quantity within the tool set reduces training time, processing time, potential damage to hardware and injury to personnel, and decreases the chance of using the wrong tool for the work. System designs and tool determinations should accommodate tool reach, grasps, and volumes of ground personnel populations, tool motions, and any concurrent flight system component volume needed around the tool use. For example, designs should account for tools being used by one person while adjacent personnel assist in securing the weight or positioning of a removable or tested component. Tool grasps, weights, tethering, and clearance may also be affected by varying postures needed for access or visibility. Integrated

task analyses should be performed to support use of common tools or determine where specialized tools may need to be pre-defined.]

12.1.3.8 Captive Fasteners

[V2 12017] Fasteners on installable units **shall** be captive.

[Rationale: A captive fastener is one that is automatically retained in a work piece when it is not performing its load-bearing job. Captive fasteners for maintenance, assembly, integration, and processing tasks, therefore, do not require ground support personnel to restrain and store them during task performance, and can more easily be installed with one hand, reducing task times and reducing the chance of fastener loss. Dropped fasteners could become Foreign Object Debris (FOD), which pose a risk during the mission. They can cause injury, impact launch schedule, and damage equipment.]

12.1.3.9 Ground Processing Without Damage

[V2 12018] The system **shall** be designed for assembly, testing and checkout, troubleshooting, and maintenance that prevents damage to other components.

[Rationale: Damage to certified flight components will cause costly recertification and may impact the launch. This requirement is intended to limit such damage and recertification by maintaining a flight configuration for all systems that are not part of the maintenance activity and providing mitigation strategies when possible. To define the necessary accommodations for maintenance without damage, an integrated task analysis has to be performed for each maintenance activity. Methods that have been successfully used to preclude damaging other components during maintenance include the following: (1) routing cables to prevent mechanical damage, pinching by doors, or twisting; (2) protecting against inadvertent actuation; and (3) implementing provisions for components that are susceptible to abuse or those frequently used.]

12.1.3.10 Replaceable Items

[V2 12019] The system **shall** locate maintenance items so that a planned ground processing or corrective or preventive maintenance task does not require the deintegration or demating of other systems or components.

[Rationale: Deintegration of certified flight components will cause costly recertification if disturbed. This requirement is intended to limit damage and recertification by maintaining a flight configuration of all systems and providing mitigation strategies when possible. Corrective maintenance is limited to LRUs, whereas preventive maintenance is a planned maintenance activity (e.g., battery replacement). To define the necessary accommodations for maintenance without damage, an integrated task analysis has to be performed for each maintenance activity.]

12.1.3.11 Visual Access for Ground Processing

[V2 12020] The system **shall** provide direct line-of-sight visual access to all flight system components requiring inspections or other human-system interactions, except self-mating connectors, on which ground processing is performed by ground personnel.

[Rationale: Direct line-of-site visual access reduces the likelihood of human error that can occur when blind (by feel) operations or operations requiring the use of specialized tools (e.g., mirrors or bore scopes) are performed. The addition of obstructions from the hands, tools, equipment, PPE (e.g., gloves, protective suits), corrective lenses, and the components or cabling needs to be considered during the line-of-sight operation. Reliance on just the "feel" of the hardware introduces human error variances. A self-mating connector is a connector that, when two pieces of hardware slide into place, they automatically self-mate. See requirement [V2 12014] Inadvertent Operation Prevention.]

12.1.3.12 Lighting

[V2 12021] The flight system in combination with ground support equipment **shall** provide lighting to perform ground processing tasks in the vehicle.

[Rationale: Lighting is required to ensure that the ground support personnel can adequately view the hardware/equipment associated with the task, and it is generally accomplished through GSE but may include flight lighting. Additionally, this may require an integrated solution, utilizing the flight vehicle and ground equipment providers. Lighting or illumination types, levels, controls, selection, and design factors should accommodate general assembly or bench work tasks down to extra fine precision while accounting for lux or lumen levels, shadow prevention, indirect and direct glare mitigations, color temperature, brightness adjustability, dark adaptation, color rendering, and lighting color techniques (e.g., red flood, low-color temperature, bright markings [foot-lamberts]). Variations in operating conditions such as natural sunlight, artificial lighting, or filtering also have to be considered.]

12.1.3.13 Supplemental Systems

[V2 12022] The system **shall** be designed to support any supplemental systems that are required to assist ground support personnel when an assigned task cannot reliably, safely, or effectively be performed by ground support personnel alone.

[Rationale: Tasks that cannot be reliably, safely, or efficiently performed by the ground support personnel are to be identified. In those cases, supplemental systems (such as GSE) will need to be accommodated in design. This may include providing attach points for GSE, rails, tracking or removal guides, and/or accommodation of ground support lighting.]

12.1.3.14 Operational Consistency

[V2 12023] The system **shall** be designed for consistent operation across ground processing tasks.

[Rationale: The intent of this requirement is to ensure commonality and consistency across flight systems. This will facilitate learning and minimize interface-induced ground support personnel error. Examples include consistent use of control direction ("on" is always "up"), "closed" direction is always the same (right), consistent use of a release mechanism, terminology, markings, color coding, etc.]

12.1.3.15 Restraints and Platforms

[V2 12024] The system **shall** accommodate restraint and platform placement that ensures the reach and work envelope of the suited or unsuited ground support personnel for the required tasks.

[Rationale: Restraints and platforms are intended to keep personnel from falling (or related hazards), allow for hardware access, and protect the hardware from inadvertent ground support personnel collision. A task analysis will identify locations where restraints and platforms are needed. A worksite analysis will inform the placement and design the restraints and platforms needed.]

12.1.3.16 System Feedback

[V2 12025] The system **shall** provide feedback to the operator indicating successful task completion.

[Rationale: Feedback can include visual indication, audible click, handle position, bolt height, alert, etc. Feedback at task completion is important to prevent continual inputs into the system, which may lead to damage to the system. For example, when filling a tank, feedback that the tank is full is important to prevent overfilling, which may result in human injury or hardware/equipment damage. If system feedback is not possible, another means of feedback is necessary (i.e., GSE). For example, if the system does not provide indication of a full tank, the equipment used to fill the tank should provide the feedback.]

12.1.3.17 Stowage Access

[V2 12026] The system **shall** provide access for ground support personnel to spacecraft stowage volumes that require late loading and early unloading of items.

[Rationale: Ground personnel are responsible for any "late loading" of items such as fresh food, pharmaceuticals, and experiment items with short lifetimes that need to be placed onboard the spacecraft within 24 hours of launch. Similarly, "early access" items need to be retrieved off the spacecraft within a short time after landing. Regular unloading requires waiting until the

spacecraft returns to the processing facility, which could be weeks later. The intent of this requirement is to allow the ground support personnel to perform these access operations safely without disruption to the space flight crew or spacecraft.]

12.1.3.18 Flight Software Systems

[V2 12027] The system **shall** allow the ground support personnel safe operation of flight software systems for ground processing.

[Rationale: Ground support personnel may be required to access flight software systems during ground operations tasks. Therefore, it is critical for flight software systems to have a mode or configuration for safe operation by ground support personnel.]

12.1.4 Safety

12.1.4.1 Sharp Edge and Burr Injury Prevention

[V2 12028] The system **shall** protect ground support personnel from injury resulting from sharp edges and burrs.

[Rationale: Protection of ground support personnel from injury controls ground operations costs by assuring that bodily fluids, such as blood, do not contaminate flight systems, degrading flight safety. In those areas that the ground support personnel would access for ground processing and maintenance, the design should protect them from burrs, sharp edges, and sharp corners. Support personnel may have an additional risk that system hardware may be in a more exposed configuration during maintenance or installation/removal operations. The intent of this requirement is for a design solution, not an operational solution, since the latter results in expensive recurring costs. The requirement might be met by rounding of edges and corners, sanding burrs, or by designing flight structure that hides sharp edges and corners and burrs from ground personnel during planned operations. It cannot be met by design of remove-before-flight protective structure.]

12.1.4.2 Pinch Point Prevention

[V2 12029] The system **shall** be designed to protect ground personnel from injury due to pinch points.

[Rationale: A pinch point can cause injury to ground personnel or damage to hardware if not protected. Pinch points may exist for the nominal function of equipment (i.e., equipment panels), but need to be covered or protected during ground operations. Injury may be avoided by locating pinch points out of the reach of the ground personnel or providing guards to eliminate the potential to cause injury.]

12.1.4.3 Hazard Controls

[V2 12030] The system **shall** be designed to prevent unnecessary exposure of ground support personnel and equipment to hazards, including spills, electrical shocks, and the release of stored energy.

[Rationale: Ground support personnel should not be exposed to hazards unnecessarily. Spill hazards can be avoided by capturing the spill or by adding extensions to the flight vehicle to relocate the hose to flight connection away from the vehicle. Electrical exposure can be avoided by shielding, interlocks, and de-energizing electrical stored energy. Interlocks should not be the sole mean of de-energizing electrical circuits of equipment and are not substitutes for lockout and tag-out procedures and practice.]

12.1.4.4 System Safing for Ground Operations

[V2 12031] The system **shall** alert and allow ground personnel to safe the system before performing any ground operation.

[Rationale: Elements or systems have to provide methods for system safing during ground assembly and maintenance activities to protect the system, hardware, and equipment from damage or personnel from injury. To ensure all areas in which a method should be in place for system safing, an integrated task analysis has to be performed. The system has to alert ground personnel of unsafe conditions. To safe or unsafe a system, a combination of mechanical actuation (physical lockout) with corresponding indicators (tagout means) should allow ground personnel to engage or disengage the system while informing personnel of safe or unsafe conditions (e.g., flashing or steady lights of various colors, distinct audio alarms, positive locking engagements, other status indicators using multiple modalities). Safing or unsafing mechanisms and controls have to be accessible to ground personnel for safe and timely execution. Methods that have been successfully used as controls for system safing include physical protection, interlocks, software disabling or multiple key combinations, cut-out switches, warning placards, and guards.]

12.1.4.5 Contamination Controls

[V2 12032] The system **shall** have controls in place to prevent the introduction of contaminants to the flight vehicle.

[Rationale: Elements or systems cannot release hazardous or non-hazardous materials into the space flight system during maintenance activities. Controls have to be designed to prevent contamination.]

12.1.4.6 Containment of Fluids and Gases

[V2 12033] The system **shall** provide for containment and disposal of the inadvertent release of fluids and gases into the flight system.

[Rationale: This can be accomplished by isolating, draining, or venting pressurized fluids. System developers are to identify the containment points and create isolation capabilities. The control valves are to be located near those service points to avoid control errors.]

12.1.4.7 Safe Weight Limit

[V2 12034] Hardware and equipment installed or removed by ground support personnel without ground support equipment **shall** be less than a safe weight limit.

[Rationale: Handling of hardware and equipment that is too heavy can result in injury or damage to the equipment (e.g., dropped hardware). NIOSH has published a lifting equation, designed to determine a recommended weight limit for safely lifting loads. It accounts for factors that would affect a person's ability to lift, including the position of the load relative to the body, the distance lifted, the frequency of lifts, and the coupling (gripping) method. These various factors need to be accounted for while determining safe weight limits for the ground support personnel during assembly, processing, and maintenance tasks. Other factors such as obstructions, surrounding environment, the carefulness needed in placing an object should also be considered in design.]

12.1.4.8 Safe Flight System Component Arrangement

[V2 12035] Flight system components **shall** be arranged, or located to prevent hazards, interference, or errors during concurrent ground processing tasks.

[Rationale: Hardware, personnel, software, and/or automation could interact in such a way during concurrent tasks as to create undesired outcomes. For example, crossing cables during installation may lead to inadvertent forces on those cables which may cause problems in-flight. The system and components should provide a means of damage detection by inspection or test and a means to recover. Consequences of errors on safety or system performance should be made clear. Placing items in view on system mold lines, rather than stacked or hidden, can provide visual indicators of damage or interferences. Obtaining a test failure should indicate the isolated area of the fault, and the system should provide physical and visual means to the affected area. For pneumatic systems, clear sight glasses have been incorporated showing mechanical indicators to clearly identify performance flow or inoperability. In software or instrumentation, system status windows with conditional indicators for online, offline, optimal, or off nominal, can provide means of detecting the failure or damage in time to recover before flight.]

12.1.5 Connectors

12.1.5.1 Connector Design and Spacing

[V2 12036] Connectors **shall** be designed and spaced to allow for accurate, damage-free mating and demating by ground support personnel.

[Rationale: Connectors need to be grasped firmly for connecting and disconnecting. The clothing, gloves, equipment, and PPE worn by the ground support personnel during the task have to be considered in design.]

12.1.5.2 Connector Incorrect Mating Prevention

[V2 12037] Connectors **shall** have physical features to preclude incorrect mating and mismating. This can be accomplished by differing connector shell sizes, differing connector keyway arrangements, and having different contact arrangements (these are listed in order of most preferred to least preferred).

[Rationale: Connector similarity could lead to inadvertent mismating, which is the mating of a male plug to the wrong female jack. Mismating can damage pins or mechanisms, or even (once powered or filled with fluids) lead to personal injury or equipment damage. Incomplete electrical connector mating can result in short circuits or open circuits. Incomplete fluid connector mates, especially in pressurized systems, can result in unexpected and possibly hazardous fluid release. Physical features such as color coding, different size connectors, connector keying, and tactile feedback can help ensure proper installation. Connector savers can be used to reduce the probability of extensive rework caused by high repetition of mating/demating or the possibility of mismating. Labels can help to identify which connector plug is intended to be mated with which jack, as well as proper orientation for mating.]

12.1.6 Labels

These requirements ensure that the design and placement of labels allow users to locate and identify controls and human interfaces, to interpret and follow procedures, or to avoid hazards. Labels may include permanent labels, placards, etchings, engravings, part markings, decals, ink-stamped labels, engraved labels, or silk-screened labels.

12.1.6.1 Label Provisions

[V2 12038] Labels and placards **shall** be provided for the ground support personnel to identify items, interpret and follow procedures, and avoid hazards.

[Rationale: Ground support personnel interface items have to have identifiers (labels) to aid in assembly, maintenance, test, and checkout operations. Labels for ground support personnel interfaces help prevent ground processing mishaps, process escapes, and human errors. Labels need to be positioned so it is intuitive which item is being identified. Labels reduce memory load

and improve accuracy of tasks. This includes, but is not limited to, identification of emergency equipment and procedures, safe weight limits, and hazards identification.]

12.1.6.2 Label Standardization

[V2 12039] Labels and placards **shall** be consistent and standardized throughout the system.

[Rationale: Systems, hardware, and equipment that are intended to be used by ground support personnel and the space flight crew need to employ standardized nomenclature, label formats, coding, language, measurement units, and icons in concordance with the space vehicle system.]

12.1.6.3 Label Content

[V2 12040] The content of labels and placards **shall** be of sufficient size, color contrast, and character height and style to support readability.

[Rationale: Labels and placards need to be readable at the intended viewing distance. Designers need to consider the distances at which the labels and placards are expected to be viewed, any worn PPE, and the lighting conditions in which the labels and placards will be viewed.]

12.1.6.4 Readable Label Positioning

[V2 12041] Labels and placards **shall** be located such that they are readable by the operator, considering ambient lighting conditions, orientation in the integrated configuration, and position of the operator relative to the label.

[Rationale: Labels and placards need to be readable in the normal operating position. Designers need to consider the lighting conditions for the operation of the hardware and make sure the labels are readable, given the task demands.]

12.1.6.5 Non-Obstructive Labels

[V2 12042] Labels, placards, or part markings used for ground processing **shall not** visually or operationally interfere with space flight crew interface labeling.

[Rationale: Space flight crew interface flight labeling has to take precedence over ground labeling to ensure safe flight operations. Interference with the flight labeling by ground labeling can cause confusion for the space flight crew. When and where possible, the ground labeling should not be visible to the crew in-flight.]

12.2 Emergency Egress Operations

The capability for ground support personnel emergency egress and access to medical care during ground processing, preflight and postflight is critical to ensure the safety and health of *ground and space flight crews. Note these requirements augment the requirement in NPR 8705.2, section 3.6.1.1, that requires the space system to provide the capability for unassisted crew emergency egress to a safe haven during Earth prelaunch activities.*

12.2.1 Emergency Egress at the Launch Site

[V2 12043] The system **shall** be designed such that the space flight crew and ground support personnel can egress within the time required to preserve the health and safety of all space flight crew and ground support personnel in the event of an emergency.

[Rationale: Space flight crew egress may require the assistance from ground support personnel, and ground support personnel may need to egress due to emergencies during processing. Ground support personnel wearing protective clothing need to be accommodated, in addition to the space flight crewmember wearing an ascent/entry suit during emergency egress scenarios. Ground support protective clothing may include a bulky backpack and air tank. Egress scenarios need to be evaluated to adequately configure the egress paths in the design.

12.2.2 Emergency Egress to Medical Care

[V2 12044] The system **shall** be designed to ensure space flight crew and ground support personnel can egress to a location providing advanced pre-hospital life support.

[Rationale: Egress systems primarily relocate personnel to a safe location. Upon an emergency egress, it is possible that medical care will be needed. An egress system that delivers personnel to a location that provides advanced pre-hospital life support is important to prevent delayed medical treatment.]

12.2.3 Nominal Timely Egress

[V2 12045] Following a post mission nominal landing, launch scrub, or abort scenario, crew egress from the system **shall** be expedited to ensure crew health.

[Rationale: Environmental, safety, and health considerations may necessitate expedited egress. For the well-being of all crewmembers, it is necessary to expedite egress. For example, it is possible that one or more crewmembers may experience health issues following a re-adaptation to Earth's gravity. In addition, following a launch scrub/mission abort, vehicle troubleshooting may be required quickly after crew egress.]

12.2.4 Emergency Egress Acceleration Limits

[V2 12046] For ground emergency egress systems (EES), the system **shall** limit the magnitude and direction of crew exposure to accelerations according to Table 36, EES Acceleration Limits – Sustained, and Table 37, EES Acceleration Limits – Jerk.

[Rationale: Emergency egress systems should provide and maintain a level of system safety sufficient to permit routine use of the system in crew training operations while ensuring that safety measures do not adversely affect the performance of the system during its intended use in emergency scenarios. Human tolerance levels and stability under acceleration vary broadly depending on the axes of acceleration, restraint type, duration, and condition of the subjects. The limits in this requirement represent safe levels of translational acceleration and start and stop changes in acceleration or jerk for the human. Exposure to acceleration above these limits could cause injury.

** This requirement may be revised based on tailoring of ASTM F2291-20, Standard Practice for Design of Amusement Rides and Devices, to be more specific to human space flight system parameters.]*

Table 36—EES Acceleration Limits - Sustained

	NASA Category 0 Standing Unrestrained with Support Aids	NASA Category 1 Seated Unrestrained without Support Aids	NASA Category 2 Seated with Sufficient Support Aids	NASA Category 3 Seated with Restraints	NASA Category 4 Seated with Full Restraints
+/- Gx (Eyeballs In/Out)	$\lvert Gx \rvert \leq 0.3g$	$-0.3g \leq Gx \leq 1.8g$ If $Gz \geq 0.7g$: $-0.45g \leq Gx \leq 1.8g$	$-0.7g \leq Gx \leq 3.0g$	$-2.0g \leq Gx \leq 4.0g$	$\lvert Gx \rvert \leq 4.0g$
+/- Gy (Eyeballs Right/Left)	$\lvert Gy \rvert \leq 0.3g$	$\lvert Gy \rvert \leq 0.3g$ If $Gz \geq 0.7g$: $\lvert Gy \rvert \leq 0.45g$	$\lvert Gy \rvert \leq 1.0g$	$\lvert Gy \rvert \leq 1.0g$	$\lvert Gy \rvert \leq 1.0g$
+/- Gz (Eyeballs Down/Up) Gravity is +1.0g (Gz)	$0.7g \leq Gz \leq 1.3g$	$0.2g \leq Gz \leq 1.5g$	$0.2g \leq Gz \leq 1.8g$	$-0.5g \leq Gz \leq 2.0g$ If time > 30s: $0g \leq Gz \leq 2.0g$	$-0.5g \leq Gz \leq 2.0g$ If time > 30s: $0g \leq Gz \leq 2.0g$

NASA Category 0 - Support aids are handhold points such as straps or handgrips. Guidance derived from U.S. Department of Transportation (DOT) Standards, 49 CFR Part II, Parts 213 and 238, DOT, Federal Railway Administration: Vehicle/Track Interaction Safety Standards; High-Speed and High Cant Deficiency Operations; Final Rule March 13, 2013. Supplemental material from Hoberock, L.L. (1976). A survey of longitudinal acceleration comfort studies in ground transportation vehicles, U.S. Department of Transportation, Office of University Research, Research Report 40.
NASA Category 1 - Assumptions are that passengers are seated with seatback and headrest. General guidance derived from ASTM F2291-20, Area 1. Supplemental material from: (1) Hoberock, L.L. (1976). A survey of longitudinal acceleration comfort studies in ground transportation vehicles, U.S. Department of Transportation, Office of University Research, Research Report 40; and (2) Abernethy, C.N., Plank, G.R., and Sussman, E.O. (1977). Effects of deceleration and rate of deceleration on live seated human subjects. U.S. Department of Transportation, Report No. UMTA-MA-06-004S-77-3.
NASA Category 2 - Plus sufficient support aids are neck support with molded headrest and lateral supports/dividers. General guidance derived from ASTM F2291-20, Area 2.
NASA Category 3 - Plus restraints are snug and padded for torso and shoulders.
NASA Category 4 - Plus restraints hold neck securely with full body stabilization fore/aft and lateral.
For the -Gx and +/-Gy requirements of NASA Category 1 and the -Gx requirement of NASA Category 2, it is assumed that the seat-suit interface has sufficient stiction and friction.
When incapacitated personnel are placed in the vehicle, if they are restrained in a secured Stokes-type litter, then Category 3 acceleration limits apply.
When incapacitated personnel are placed in the vehicle in a seated position, if Category 4 restraints are used, then Category 4 acceleration limits apply.
In all other scenarios for incapacitated personnel, Category 0 acceleration limits apply, and appropriate methods should be used to minimize their motion during the ride.
Verification will determine whether any of the sustained acceleration limits in above table are exceeded for more than 200ms for any passenger, given their assumed orientation and level of restraint. Per ASTM F2291-18, Section 7.1.1.2, all measured or simulated acceleration time histories will be postprocessed using a 4th-order, single pass, Butterworth low-pass filter with a corner frequency of 5 Hz.

Table 37—EES Acceleration Limits - Jerk

	NASA Category 0 Standing Unrestrained with Support Aids	NASA Category 1 Seated Unrestrained without Support Aids	NASA Category 2 Seated Unrestrained with Sufficient Support Aids	NASA Category 3 Seated with Restraints	NASA Category 4 Seated with Restraints
dGx/dt	3g/s	10g/s	20g/s	30g/s	40g/s
dGy/dt	3g/s	3g/s	10g/s	10g/s	10g/s
dGz/dt	4.5g/s	10g/s	12g/s	20g/s	20g/s
Verification will determine whether any of the sustained acceleration limits in Table 37 are exceeded for more than 200 ms for any passenger, given their assumed orientation and level of restraint. Per ASTM-F2291-20, section 7.1.1.2, all measured or simulated acceleration time histories will be post processed using a 4th-order, single pass, Butterworth low-pass filter with a corner frequency of 5 Hz.					

APPENDIX A

REFERENCE DOCUMENTS

A.1 PURPOSE

This Appendix provides guidance made available in the reference documents listed below. Reference documents may be accessed at https://standards.nasa.gov, obtained directly from the Standards Developing Body or other document distributors, obtained from information provided or linked, or by contacting the Center Library or office of primary responsibility.

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

A.2 REFERENCE DOCUMENTS

A.2.1 Government Documents

Department of Defense

SS521-AG-PRO-010	U.S. Navy Diving Manual
MIL-HDBK-1908	Definitions of Human Factors Terms
MIL-STD-1472	Department of Defense Design Criteria Standard, Human Engineering
MIL-STD-1474, most current revision	Department of Defense Design Criteria Standard, Noise Limits

Federal

29 U.S.C. §1915.12(a)(2), Precautions and the order of testing before entering confined and enclosed spaces and other dangerous atmospheres, March 28, 2017

49 CFR Part II, Parts 213 and 238, U.S. Department of Transportation (DOT) Standards, Federal Railway Administration: Vehicle/Track Interaction Safety Standards; High-Speed and High Cant Deficiency Operations; Final Rule March 13, 2013

Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (UN, 1967), Article IX

OMB Circular No. A-119	Federal Participation in the Development and Use of Voluntary Consensus Standards and in Conformity Assessment Activities, as revised January 27, 2016, at Federal Register Vol. 81, No. 17, page 4673, accessible at https://www.whitehouse.gov/wp-content/uploads/2020/07/revised_circular_a-119_as_of_1_22.pdf
Electronic Code of Federal Regulations	1910.146(b)(3), Permit-required confined spaces. Current through July 29, 2021
The National Institute for Occupational Safety and Health (NIOSH)	Criteria For a Recommended Standard: Occupational Noise Exposure https://www.cdc.gov/niosh/docs/98-126/pdfs/98-126.pdf?id=10.26616/NIOSHPUB98126
World Health Organization (WHO)	Exposure Criteria, Occupational Exposure Levels https://www.who.int/occupational_health/publications/noise4.pdf
Environment, Health & Safety	Biological Exposure Indices® (BEIs), sections Light and Near-Infrared Radiation and Ultraviolet Radiation (2014 or later).
Occupational Safety and Health Administration (OSHA)	Policy on Indoor Air Quality: Office Temperature/Humidity and Environmental Tobacco Smoke, 2003 https://www.osha.gov/laws-regs/standardinterpretations/2003-02-24
Centers for Disease Control and Prevention (CDC)	Perceived Exertion (Borg Rating of Perceived Exertion Scale) https://www.cdc.gov/physicalactivity/basics/measuring/exertion.htm

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Clarke, J.M. Oxygen Toxicity (Chapter 6). The Physiology and Medicine of Diving (4th ed), Bennett, P.B., Elliott, D.H. (eds). W.B. Saunders Company Ltd: Philadelphia, 1993, pp. 153-69)

Deliberations of the Exploration Atmospheres Working Group (EAWG), 2006

Human Exploration and Operations Mission Directorate (HEOMD) memo, Exploration Atmospheres, February 2013

Operational and Research Musculoskeletal Summit, August 23-25, 2005, Space Center, Houston, TX (https://ntrs.nasa.gov/api/citations/20070031573/downloads/20070031573.pdf)

	Nutrition Requirements, Standards, and Operating Bands for Exploration Missions, December 2005. Johnson Space Center, Scott M. Smith
EC-09-154	Bue, Grant C., Lyndon B. Johnson Space Center Memorandum, Tolerable Limit for Hand Skin Temperatures in Glove Tests, November 3, 2009
EVA-EXP-0035	Exploration EVA System Compatibility
SA-12-067	Level II Johnson Space Center (JSC) Chief Medical Officer (CMO) Health and Medical Technical Authority (HMTA) Position on Potential Atmospheres for Exploration, August 8, 2012
SA-16-156	Level II JSC CMO HMTA Position on NHV and Internal Layout Considerations for Exploration Missions
JSC-27260	Standard Flight Decal Catalog (https://www.nasa.gov/centers/johnson/pdf/495093main_Decal-Catalog-JSC-27260-RevF.pdf)
JSC-27472	Requirements for Submission of Data Needed for Toxicological Assessment of Chemicals and Biologicals to be Flown on Manned Spacecraft (https://www.nasa.gov/sites/default/files/atoms/files/jsc_form_27472.pdf)
JSC-39116	EMU Phase VI Glove Thermal Vacuum Test and Analysis Final Report, Doc. #CTSD-SS-1621, NASA Johnson Space Center, August 20, 1998
JSC-63414	Spacecraft Water Exposure Guidelines (SWEGs) (https://www.nasa.gov/sites/default/files/atoms/files/jsc_63414_final_with_signature.pdf)
JSC-63557	Net Habitable Volume Verification Method
JSC-65829	Loads and Structural Dynamics Requirements for Space flight Hardware (https://ntrs.nasa.gov/api/citations/20110015359/downloads/20110015359.pdf)
JSC-66320	Optical Property Requirements for Glasses, Ceramics, and Plastics in Spacecraft Window Systems

	(https://forum.nasaspaceflight.com/index.php?action=dlattach;topic=51325.0;attach=1945174;sess=0)
JSC-CN-19414	Assessment of Prone Positioning of Restrained, Seated Crewmembers in a Post Landing Stable 2 Orion Configuration (https://ntrs.nasa.gov/citations/20100005137)
NASA/SP-2010-3407	Human Integration Design Handbook (HIDH) (https://www.nasa.gov/sites/default/files/atoms/files/human_integration_design_handbook_revision_1.pdf)
NASA/SP-6105	NASA Systems Engineering Handbook (https://ntrs.nasa.gov/citations/20170007238)
NASA-STD-6016	Standard Materials and Processes Requirements for Spacecraft
NASA/TM-2007-214755	The Apollo Medical Operations Project: Recommendations to Improve Crew Health and Performance for Future Exploration Missions and Lunar Surface Operations (https://ntrs.nasa.gov/citations/20070030109)
NASA/TM-2008-215198	The Use of a Vehicle Acceleration Exposure Limit Model and a Finite Element Crash Test Dummy Model to Evaluate the Risk of Injuries during Orion Crew Module Landings (https://ntrs.nasa.gov/citations/20080018587)
NASA/TM-2013-217380	Application of the Brinkley Dynamic Response Criterion to Spacecraft Transient Dynamic Events (https://ntrs.nasa.gov/citations/20170005913)
NASA/TM-2020-220525	Standard Testing Procedure for Quantifying Breathing Gas Carbon Dioxide Partial Pressure for Extravehicular Activity and Launch, Entry, Survival Pressure Suits (https://ntrs.nasa.gov/api/citations/20200002476/downloads/20200002476.pdf)
NASA/TM-20205008196	Artemis Sustained Translational Acceleration Limits: Human Tolerance Evidence from Apollo to International Space Station (https://www.nasa.gov/sites/default/files/atoms/files/lunar_transient_accel_tm.pdf)
NASA-TN-D-5153	The Use of Pilot Rating in the Evaluation of Aircraft Handling Qualities (https://ntrs.nasa.gov/citations/19690013177)

NASA/TP-2014-218556	Human Integration Design Processes (HIDP) (https://ntrs.nasa.gov/citations/20140009559)
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NPR 7123.1	NASA Systems Engineering Processes and Requirements
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NPR 8715.3	NASA General Safety Program Requirements
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APPENDIX B

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

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

~	approximately
β	beta, injury risk criterion
°	degree
Δ	delta (change)
ΔQ	delta Q
=	equal
>	greater than
≥	greater than or equal to
<	less than
≤	less than or equal to
-	minus
μg	microgram
μ	mu, micro
μm	Micrometer
μPa	micropascal
Ω	omega, ohm
%	percent
+	plus
±	plus or minus
θ	theta, angle of incidence
ρ	rho, density
A	ampere
A/m	ampere per meter
AC	alternating current
ACGIH	American Conference of Governmental Industrial Hygienists
AGARD	Advisory Group for Aerospace Research and Development
ALARA	as low as reasonably achievable
ANSI	American National Standards Institute
APP	Applicable
Ar	Argon
ARS	atmosphere revitalization system
ASA	Acoustical Society of America
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
B/W	black and white
BEI	biological exposure index (indices)
BET	Blur Edge Time

bpm	beats per minute
BSL	biosafety levels
Btu	British thermal unit
c	specific heat
C	Celsius
cal	calorie
CCP	Commercial Crew Program
CCT	Correlated Color Temperature
cd	candela
CDO	cognitive deficit onset
CFR	Code of Federal Regulations
CFU	colony forming unit
CIE	International Commission on Illumination
cm	centimeter
cm^2	square centimeter
CMO	Chief Medical Officer
C_n	minutes of noise exposure
CO_2	carbon dioxide
COAS	Crew Optical Alignment System
Comm	Communication
COSPAR	Committee for Space Research
COTS	Commercial Off-the-Shelf
CP	combustion product
CQS	Color Quality Scale
CRI	Color Rendering Index
D	noise dose
dB	decibel
dBA	decibels, A-weighted
DC	direct current
DCS	decompression sickness
Deg	Degree
DER	Daylight Equivalent Ratio
DMS	Display Measurement Standard
DNA	deoxyribonucleic acid
DOT	Department of Transportation
DRI	dietary reference intake
DRM	Design Reference Mission
E	perceptual distance between colors
	electric field strength
EAWG	Exploration Atmospheres Working Group
ECG	electrocardiogram
ECLSS	Environmental Control and Life Support System
EDI	Equivalent Daylight Illuminance
EER	estimated energy requirements
EES	emergency egress systems

EMU	extravehicular mobility unit
ETEC	Enterotoxigenic Escherichia coli
EVA	extravehicular activity
F	Fahrenheit
f	frequency
f_G	frequency in gigahertz
F_i	Fractional concentration of inspired oxygen
f_M	frequency in megahertz
FFRDC	Federally Funded Research and Development Center
fl	fluid
fl oz	fluid ounce
FOD	Foreign Object Debris
FPDM	Flat Panel Display Measurements
ft	foot, feet
G	gravitational constant
g	gram
	gravity (gravity equals 9.8 m/s^2)
GCR	galactic cosmic ray
GET	Gaussian Edge Time
GHz	gigahertz
GSE	Ground Support Equipment
GUI	graphical user interface
+/- Gx	Eyeballs in/out
+/- Gy	Eyeballs right/left
+/- Gz	Eyeballs down/up
H	magnetic field strength
HCD	human-centered design
HDBK	Handbook
He	Helium
HEI	human error identification
HeNe	helium-neon
HEOMD	Human Exploration and Operations Mission Directorate
HEPA	high efficiency particulate air
HIDH	Human Integration Design Handbook
HIDP	Human Integration Design Processes
HITL	human in the loop
HMTA	Health and Medical Technical Authority
HQR	Handling Qualities Rating
hr	hour
HRL	hazard response level
HSI	human systems integration
HSIP	Human Systems Integration Plan
HUD	head’s up display
Hz	Hertz
ICDM	International Committee on Display Metrology

ICR	Incapacitated Crew Rescue
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IES	Illuminating Engineering Society
IMV	inter-module ventilation
in	inch
IPR	intellectual property rights
IR	infrared
IRD	Information Requirements Document
ISO	International Organization for Standardization
ISS	International Space Station
IVA	intravehicular activity
J	Joule
JPR	Johnson Procedural Requirements
JSC	Johnson Space Center
K	Kelvin
k	kilo
	thermal conductivity
kcal	kilocalorie
kg	kilogram
kHz	kilohertz
kJ	kilojoule
km	kilometer
kPa	kilopascal
L	liter
LADTAG	Lunar Atmosphere Dust Toxicity Assessment Group
lb	pound
LEA	launch, entry and abort
LED	light-emitting diodes
LEO	low Earth orbit
LIA	Laser Institute of America
LiOH	lithium hydroxide
L_n	sound level of a noise exposure event in dBA
LN,A	A-weighted sound level of the ambient noise
LOC	loss of crew
logMAR	Logarithm of the Minimum Angle of Resolution
LOM	loss of mission
LRU	Line Replacement Unit
LS,A	A-weighted sound level of the auditory annunciation or signal
LSi,oct	Octave band sound pressure level corresponding to the auditory annunciation or signal
LSi, 1/3oct	1/3 octave band sound pressure level corresponding to the auditory annunciation or signal

Lti,1/3oct	1/3 octave band sound pressure level corresponding to the effective masked threshold
m	meter
m^3	cubic meter
MΩ	megaohm
mA	milliampere
ma	maximum current
Max	maximum
mg	milligram
MHz	megahertz
MIL	Military
min	minute
mL	milliliter
mm	millimeter
MH	Monomethyl hydrazine
MMH	Manual Materials Handling
mmHg	millimeter of mercury
MMOD	Micrometeoroids and Orbital Debris
MORD	Medical Operations Requirements Document
MPE	maximum permissible exposure
ms	millisecond
MSFC	Marshall Space Flight Center
N	number of noise exposure events in a 24-hour period
N_2	Nitrogen
N/A	not applicable
NASA	National Aeronautics and Space Administration
NC	noise criterion normal condition
NEMA	National Electrical Manufacturers Association
NHV	Net habitable volume
NIOSH	National Institute for Occupational Safety and Health
nm	nanometer
NPD	NASA Policy Directive
NPR	NASA Procedural Requirements
O_2	oxygen
OCHMO	Office of the Chief Health and Medical Officer
Oct	octave
OMB	Office of Management and Budget
OSHA	Occupational Safety and Health Administration
oz	ounce
Pa	Pascal
PA	potentially applicable
PB	Ambient Barometric Pressure
PDA	personal digital assistant
PEL	permissible exposure limit

P_ICO_2	inspired carbon dioxide partial pressure
P_IO_2	inspired oxygen partial pressure
pp	partial pressure
ppm	parts per million
$ppCO_2$	partial pressure of carbon dioxide
PPE	Personal Protective Equipment
ppO_2	partial pressure of oxygen
psi	pound(s) per square inch
psia	pound(s) per square inch absolute
PWD	potable water dispenser
Q	heat
rad/s^2	radians per second squared
REID	risk of exposure-induced death
RF	radio frequency
Rg	color gamut index
RH	relative humidity
RMS	root mean square
RPE	Rating of Perceived Exertion
rpm	revolutions per minute
s	second
S	power density
SA	situational awareness
SAS	space adaptation syndrome
SDS	Safety Data Sheet
sec	second
SI	International System of Units
SIL	speech interference level
SMAC	spacecraft maximum allowable concentration
SP	special publication
SPE	solar particle event
SPL	sound pressure level
SRD	System Requirements Document
SSP	Space Station Program
STD	Standard
STS	Space Transportation System
SUS	system usability scale
SWEG	spacecraft water exposure guideline
TLV	threshold limit value
TM	technical memorandum
T_n	maximum noise exposure duration allowed
TP	technical publication
TWA	time-weighted average
UDMH	unsymmetrical dimethylhydrazine
UN	United Nations
U.S.	United States

UV	ultraviolet
u'v'	uniform-chromaticity scale (CIE 15.2, Colorimetric 2nd ed. Commission International d l' Cellarage, Vienna Austria 1986)
V	Volt
	volume
V/m	volt(s) per meter
V1	Volume 1 (in designating numbered requirements)
V2	Volume 2 (in designating numbered requirements)
VESA	Video Electronics Standards Association
VGE	venous gas emboli
VOC	volatile organic compound
V_u	urinary output volume
W	watt
WHC	waste and hygiene compartment
WHO	World Health Organization
W/m	watt(s) per meter
W/m^2	watt(s) per meter squared
y	year

APPENDIX C

DEFINITIONS

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

Accessibility: A design feature referring to the ability to see and maneuver within a spatial volume for the purpose of operating, cleaning, retrieving, or maintaining parts of a subsystem.

Activity Center: A specific location uniquely configured for a human activity such as personal hygiene, body waste, food, sleep, trash, stowage, and exercise countermeasures.

Acute Field of View: The region of visual angle in which acuity remains at least half its maximum. It is about 3 degrees in diameter.

Advisory: A message that indicates a safe or normal configuration, indicates safe or normal operation of essential equipment, or imparts information for routine action purposes.

Affect: Observable behavior that represents the expression of a subjectively experienced feeling state (mood, morale). Common examples of affect are sadness, fear, joy, and anger. The normal range of expressed affect varies considerably between different cultures and even within the same culture.

All Mission Systems: Includes terrestrial ground control centers, other spacecraft on an occupied planetary body, other orbiting spacecraft, and other locations onboard a spacecraft.

Anthropogenic: Induced or altered by the presence of humans.

Anthropometry: The science of measuring the human body and its parts and functional capabilities. Includes lengths, circumferences, body mass, etc.

Attenuation: Diminution in force or intensity of sound.

Automatic: Pertaining to a function, operation, process, or device that, under specified conditions, functions without intervention by the crew.

Automation: (1) The implementation of a process by automatic means. (2) The theory, art, or technique of making a process more automatic. (3) The investigation, design, development, and application of methods of rendering processes automatic, self-moving, or self-controlling.

Biomechanics: The study of the principles and relationships involved with muscular activity.

Blur Edge Time (BET): A measure of the amount of motion blur on an electronic display, especially liquid crystal display. This metric is defined in ICDM-DMS 1.0.

Body-Referenced Interfaces: Interfaces that are controlled by the dynamic movements of the human body such as virtual environments.

Broad Spectrum: A spectrum or list of a sufficient number of target compounds anticipated from all expected off-nominal events.

Capability: Having attributes (such as physical or cognitive) required for performance.

Catastrophic: (1) A hazard that could result in a mishap causing fatal injury to personnel and/or loss of one or more major elements of the flight vehicle or ground facility. (2) A condition that may cause death or permanently disabling injury, major system or facility destruction on the ground, or loss of crew, major systems, or vehicle during the mission (NPR 8715.3, NASA General Safety Program Requirements).

Caution: Notification of an event that needs attention but not immediate action.

Clear Viewing Aperture: The area of a window that is not covered by the window assembly frame or other structure that would block incident light rays.

Cognitive: Pertaining to the mental processes of perception, learning, memory, comprehension, judgment, and reasoning.

Color Discrimination: The ability to distinguish between pairs of colors that span the space of colors under standard viewing conditions. The International Commission on Illumination (CIE) has defined ΔE units that specify the perceptual distance between colors.

Communication Systems: Communication systems include information provided to and from the crew by way of voice, text, video, and/or telemetry.

Contamination: The act of rendering unfit for use by the introduction or deposition of unwholesome or undesirable, usually foreign, elements.

Contingency: An off-nominal situation that is identified in the hazard analysis process and has a preplanned response to mitigate the risks to crew and/or vehicle.

Continuous Noise: Noise that exists in a steady state for durations of more than 8 hours in a 24-hour period. Typical continuous sources of noise include environmental control equipment and avionics equipment (e.g., fans, pumps, ventilation systems).

Countermeasures: A means to offset undesirable physical, physiological, and psychological effects of space flight on humans.

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

Crewmember: An individual member of a crew.

Crew Station: A location in a vehicle or habitat where crewmembers perform an activity.

Critical: A condition that may cause severe injury, occupational illness, or major property damage to facilities, systems, or flight hardware (NPR 8715.3); also of essential importance, vital, or indispensable as in “critical” design parameters. Frequently used in this NASA Technical Standard to cover both “critical” (as defined above) and “catastrophic.”

Decompression: The act or process of reduction of pressure, as occurs when releasing compressed air from a vehicle or habitat to the vacuum of space.

Decompression Sickness: A sickness induced by too rapid a decrease in atmospheric pressure sufficient to cause bubbles to form from gases (normally nitrogen [N_2]) dissolved in blood and other body tissues.

Deconditioned Crew (deconditioning): Decreased functionality of physiological systems, e.g., musculoskeletal, cardiovascular, vestibular, and nervous systems, related to adaptation to reduced gravity.

Dedicated Equipment Work Volume: Volume that cannot have multi-use but must be associated full-time with the equipment (such as interior volume of glove box, etc).

Diffuse Reflectance: The fraction of incident electromagnetic radiation such as light or other type of wave within a specified wavelength band that is reflected from a surface uniformly in all directions, regardless of the angle of incidence of the incident waves or rays. A truly diffusely (Lambertian) reflective surface has the same luminance (appears to have the same brightness) from all viewpoints, regardless of the direction of the source relative to the surface. This type of reflection is associated with matte or “flat” surface treatments on objects and is contrasted with specular reflectance. Most surfaces exhibit a combination of specular and diffuse reflectance.

Display: Anything that provides visual, auditory, and/or haptic information to crewmembers, e.g., label, placard, tone, or display device. The term “display” includes text-based user interfaces, as well as Graphical User Interfaces (GUIs).

Display Device: The hardware used to present visual, aural, and tactile information to the crew or ground operations personnel. Display devices include computer monitors and Personal Digital Assistants (PDAs).

Doors: A moveable physical barrier that acts to provide physical separation between areas or to provide privacy. Examples of doors include enclosures for an unpressurized payload bay, or a privacy divider for a personal crew quarter or hygiene area.

Doorway: The opening, the area of the vehicle, that houses the doors.

Drag Through: Any item that inhibits hatchway function by interfering with the clear passage through the hatchways including, but not limited to, cargo, cables, and wires.

Effective Masked Threshold: The level of auditory danger signal just audible over the ambient noise, taking account of the acoustic parameters of both the ambient noise in the signal reception area and the listening deficiencies (hearing protection, hearing loss, and other masking effects). The method for calculating the masked threshold is given in ISO 7731:2003(E) Annex B.

Error: Either an action that is not intended or desired by the person or a failure on the part of the person to perform a prescribed action within specified limits of accuracy, sequence, or time that does not produce the expected result and has led or has the potential to lead to an unwanted consequence.

Emergency: Time-critical event that requires immediate action and crew survival procedures.

Emergency Equipment: A set of components (hardware and/or software) used to mitigate or control hazards, after occurrence, which present an immediate threat to the crew or crewed spacecraft. Examples include fire suppression systems and extinguishers, emergency breathing devices, and crew escape systems (NPR 8705.2).

Emergency Only Controls: Controls that are only used during emergencies, e.g., eject, abort.

Equipment: Items such as tools used to accomplish a task or activity. Equipment is a type of hardware, and therefore this term is sometimes used interchangeably with hardware.

EVA Spacesuit System: Any spacesuit system designed to allow astronauts to perform tasks outside of a spacecraft or habitat. Performance of space flight EVA consists of placing a human in a micro-environment that has to provide all the life support, nutrition, hydration, waste, and consumables management function of an actual space vehicle, while allowing crewmembers to perform mission tasks. EVA spacesuits are designed to be used for durations of less than a day due to potential human and suit system constraints. This includes all suited phases (e.g., prebreathe, leak checks, airlock depress, repress).

Extraterrestrial: To be from outside Earth or its atmosphere (moon, planetary, asteroid, etc.).

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

Fatigue: Weariness, exhaustion, or decreased attention related to labor, exertion, or stress. May also result from lack of sleep, circadian shifts, depression, boredom, or disease. May result in decreased ability to perform mental or physical tasks.

Field of Regard: The solid angle that can be seen by an observer with eye and head movements.

Field of View: The solid angle that can be seen at one time by the stationary eye. It is about 150 degrees horizontally by 125 degrees vertically. When the two eyes operate together, the horizontal extent enlarges to about 190 degrees.

Field of View for Windows: All points through a window that can be viewed directly by at least one eye, given the combination of achievable eye, head, and body movement. The field of view is restricted by obstructions imposed by the facial structure around the eye and/or placed in front of the eye such as the crewmember's helmet if worn, mullions, structure, and/or other equipment. Achievable movement varies for different flight phases and operational tasks and is dependent on any constraints to movement that are extant such as being suited, seated, and/or restrained, and any g-loads present. With respect to line-of-sight phenomena such as contamination deposition and pluming, any point outboard of the window that is above the plane of the outer surface of the outermost pane of the window port is considered within the field of view of the window.

Gaussian Edge Time (GET): A measure of the amount of motion blur on an electronic display, especially a liquid crystal display. This metric is defined in ICDM-DMS 1.0.

Ground Support Personnel: Human team of one or more members supporting a mission from the ground during preflight, in-flight, surface, and post flight operations.

Ground Support Operations: Operations and tasks performed by ground personnel utilizing space flight systems, hardware, and equipment at times other than during space flight such as before launches and after landings.

Habitability: The state of being fit for occupation or dwelling. Meeting occupant needs of health, safety, performance, and satisfaction.

Habitat: A type of spacecraft, not normally mobile, that has the conditions necessary to sustain the life of the crew and to allow the crew to perform their functions in an efficient manner.

Habitable Atmosphere: The composition of the breathable environment within the Habitable Volume.

Habitable Volume: The measure of space livable and functionally usable to crew within a pressurized volume after accounting for all installed hardware and systems.

Hardware: Individual components of equipment, including but not limited to, fasteners, panels, plumbing, switches, switch guards, and wiring. This term is sometimes used interchangeably with equipment.

Hatch: An operable, sealable cover that separates two adjoining environments and allows physical passage of people and/or material from one environment to the other. Hatches can maintain pressurized environments. Hatches may function as ingress/egress points for crew prior to launch, postlanding, and for EVAs, and may also serve as connections between modules in a spacecraft.

Hatch Cover: A protective encasement that protects the hatch from unwanted exposure.

Hatchway: The opening, the area of the vehicle that houses the hatch.

Human Factors: The scientific discipline concerned with the understanding of interactions among humans and other elements of a system and the profession that applies theory, principles, data, and other methods to design to optimize human well-being and overall system performance.

Impulse Noise: A burst of noise, which exists for 1 second or less, that is at least 10 dB above the background noise.

Information Management: The act of performing functions with electronic data, including data input, organization, internal processing, storage, distribution, saving, and disposal of information about the system. Information management functions are typically performed by crew and ground personnel using displays on display devices.

Interpretable: Capable of being explained or told the meaning of; translated into intelligible or familiar language or terms.

Ionizing Radiation: Radiation that converts impacted items wholly or partly into ions (electrically charged particles). The particulate radiation component includes all subatomic particles such as protons, neutrons, electrons, atomic nuclei stripped of orbital electrons, mesons, etc.

Intravehicular Activity: Operations performed by crew within the pressurized environment of a spacecraft during a mission.

Intermittent Noise: Noise that is generated for operational durations of 8 hours or less in a 24-hour period. Typical intermittent sources of noise are waste control system components (pumps, fans, separators, valves), exercise equipment (treadmill, cycle ergometer), galley fans, personal hygiene station components (pumps, fans, valves), and pressure regulators.

LEA/IVA Spacesuit System: Any spacesuit system designed for use during launch, entry, and abort phases of space flight, primarily to protect against toxic exposure, ebullism, hypoxia, and decompression sickness in the event of an unplanned cabin depressurization or toxic release into the cabin. It may also be worn during other dynamic phases of flight such as rendezvous and docking during which there is an increased risk of cabin depressurization due to cabin leaks. The duration for which LEA spacesuits are designed to operate will depend on mission scenarios and may range from a few hours to several days per use.

Linear Acceleration: The rate of change of velocity of a mass, the direction of which is kept constant.

Local Vertical: Achieved by a consistent arrangement of vertical cues within a given visual field to provide a definable demarcation at the crew station boundary within the visual field. A consistent local vertical within modules is highly desirable.

Maintenance: All actions necessary for retaining material in (or restoring it to) a serviceable condition. Maintenance includes servicing, repair, modification, modernization, overhaul, inspection, condition determination, corrosion control, and initial provisioning of support items (MIL-HDBK-1908B, Definitions of Human Factors Terms).

Mission: A major activity required to accomplish an Agency goal or to effectively pursue a scientific, technological, or engineering opportunity directly related to an Agency goal. Mission needs are independent of any particular system or technological solution.

Mission Duration: The total time the crew is away from the surface of Earth, measured from launch of the Earth launch vehicle to landing or splashdown of the Earth return spacecraft. If the crew transfers between multiple spacecraft during this mission, except where indicated otherwise in these standards, every spacecraft the crew inhabits is subject to the requirements identified for the mission duration.

Monitoring: Includes checking for quality or fidelity; testing to determine if a signal comes within limits; watching and observing for a specific signal or purpose; keeping track of, regulating, or controlling.

Net Habitable Volume (NHV): The functional volume left available on a spacecraft after accounting for the loss of volume caused by deployed equipment, stowage, trash, and any other items that decrease the functional volume.

Noise: Sound in the auditory range (15 Hz to 20,000 Hz) that is hazardous, undesired, and/or inappropriate to the intended use of the space. In this NASA Technical Standard, the word "noise" is used interchangeably with “sound” and is not intended to convey any relative or absolute degree of hazard or other acoustical characteristic.

Nominal: Within expected, acceptable operational limits or in accordance with planned operational concepts; normal, satisfactory (aerospace usage).

Non-Habitable Volume: is defined as the portion of Pressurized Volume taken up by fixed outfitting, equipment, stowage, and dedicated equipment work volumes.

Non-Ionizing Radiation: Includes three categories of electromagnetic radiation: RF radiation, lasers, and incoherent electromagnetic radiation.

Off-Nominal: Outside of expected, acceptable operational limits or not in accordance with planned operational concepts; anomalous, unsatisfactory (aerospace usage).

Operation: An activity, mission, or maneuver, including its planning and execution.

Perception: The process of acquiring knowledge about environmental objects and events by extracting and processing the information received through the senses.

Personal Protective Equipment (PPE): Equipment that is worn to minimize exposure to a variety of hazards. Examples of PPE include such items as gloves, foot and eye protection, hearing protection devices (earplugs, muffs), hard hats, respirators, and full body suits.

Potable Water: Water that is suitable, safe, or prepared for drinking.

Pressurized Volume: The total volume within a pressure shell.

Privacy: Having an acceptable level of control over the extent of sharing oneself (physically, behaviorally, or intellectually) with others. Acceptable level is dependent upon an individual's background and training.

Program: A strategic investment by a Mission Directorate or Mission Support Office that has a defined architecture and/or technical approach, requirements, funding level, and a management structure that initiates and directs one or more projects. A program defines a strategic direction that the Agency has identified as critical.

Project: A space flight project is a specific investment identified in a Program Plan having defined requirements, a life-cycle cost, a beginning, and an end. A project also has a management structure and may have interfaces to other projects, agencies, and international partners.

Psychomotor: Of or relating to muscular action believed to ensue from conscious mental activity.

Reflectance: The fraction or percentage of incident electromagnetic radiation such as light or other type of wave at a specified wavelength that is reflected from a surface. (See also "specular reflectance" and "diffuse reflectance.")

Regolith: Unconsolidated residual or transported material that overlies the solid rock on the Earth, Moon, or a planet.

Rotational Acceleration: The rate of change of angular velocity.

Safe: Freedom from those conditions that can cause death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment.

Sensory: The information-gathering abilities of humans to see, hear, touch, smell, and taste. Includes temperature, pain, kinesthesia, and equilibrium.

Situational Awareness: Comprehension of information about an environment, evaluating the current situation with respect to goals, and projecting the evolution of the situation into the future.

Sound Quality: Those features of a sound that contribute to the subjective impression made on a listener, with reference to the suitability of the sound for a particular set of design goals. It is meant particularly to account for aspects of communication systems that are not quantifiable by intelligibility measurements.

Spacecraft: A habitable vehicle or device, including, but not limited to, orbiters, capsules, modules, landers, transfer vehicles, rovers, EVA suits, and habitats designed for travel or operation outside Earth's atmosphere.

Space flight: A process that begins when the crew has boarded the spacecraft on Earth and the hatch is closed and terminates when the spacecraft has returned to Earth, and all of the crew have egressed the spacecraft and are in the care of ground personnel. In the event of a launch abort, space flight continues until all crew have been returned to the care of ground personnel.

Spatial Contrast Sensitivity: Defined by the inverse of the smallest contrast of a spatial sinusoidal luminance grating that can be detected, at each spatial frequency, under standard viewing conditions. Peak contrast sensitivity is about 500, and the highest frequency visible is about 60 cycles/deg.

Specular Reflectance: The perfect, mirror-like reflection of an incident wave or ray such as light from a surface, in which the wave or ray from a single incoming direction is reflected into a single outgoing direction as described by Snell's Law (θi (theta i) = θr (theta r)). Diffuse reflection, on the other hand, refers to light that is reflected in a broad range of directions. (See "diffuse reflectance.") The most familiar example of the distinction between specular and diffuse reflection in the case of light waves would be glossy and matte paints or photo prints. While both finishes exhibit a combination of specular and diffuse reflectance, glossy paints and photo prints have a greater proportion of specular reflectance, and matte paints and photo prints have a greater proportion of diffuse reflectance. Anti-reflection coatings reduce the amount of light that is reflected from a given surface. Reflectance for an uncoated glass surface is ~4%, which yields ~8% for the two surfaces of a single "pane." Anti-reflective coatings can reduce the total reflectance to ~2% or less.

Standard: The definition of a "standard" is described as follows:

a. The term "standard," or "technical standard," includes all of the following: (1) Common and repeated use of rules, conditions, guidelines or characteristics for products or related processes and production methods, and related management systems practices; (2) The definition of terms; classification of components; delineation of procedures; specification of dimensions, materials, performance, designs, or operations; measurement of quality and quantity in describing materials, processes, products, systems, services, or practices; test methods and sampling procedures; formats for information and communication exchange; or descriptions of fit and measurements of size or strength; and, (3) terminology, symbols, packaging, marking or labeling requirements as they apply to a product, process, or production method.
b. "Performance standard" is a standard that states requirements in terms of required results, but without stating the methods for achieving required results; may define the functional requirements for the item, operational requirements, and/or interface and interchangeability characteristics; also may be viewed in juxtaposition to a prescriptive standard.
c. "Non-government standard" is a standard as defined above that is in the form of a standardization document developed by a private sector association, organization, or technical society that plans, develops, establishes, or coordinates standards, specifications, handbooks, or related documents.

Standardize: To make uniform.

Stereoscopic Depth Perception: The ability to distinguish objects at different depths as a result of their different positions (disparities) in the two eyes.

Suited: Wearing clothing that is designed to protect the crewmember from differences in environment such as pressure, atmosphere, acceleration, or temperature. "Suited" can refer to both pressurized and unpressurized pressure suits.

Sustained Accelerations: Events, linear or rotational, with a duration of greater than 0.5 seconds.

System: The combination of elements that function together to produce the capability to meet a need. The elements include all hardware, software, equipment, facilities, personnel, processes, and procedures needed for this purpose. (Source: NPR 7120.7, NASA Information Technology and Institutional Infrastructure Program and Project Management Requirements.)

Tailoring: The process by which requirements are derived for a specific system. This process involves two steps:

a. Selecting applicable requirements - Not all requirements within a Standard may apply to all systems. Systems are defined by parameters such as the number of crewmembers, mission duration and operations, gravity environment, and EVA activities. Some requirements apply to only some parameters. For example, mission duration may influence the volume dedicated for certain crew functions such as crew sleep and hygiene. Or the operational gravity environment may influence which requirements are applicable such as a lunar surface rover would not have met the microgravity requirements.
b. Creating requirements that can be verified - Some requirements use general terms such as “effective.” When tailoring for a specific system, these terms are then defined with values that are objective and measurable. The tailored requirement has to comply with the intent of the general requirement. For example, analysis of a specific system may show that a critical task has to be performed in less than 20 seconds. In the tailoring process, the word “effective” would be replaced by words that limit critical task performance times to 20 seconds.

Task: A specific type, piece, or amount of work; a subset of an activity or job that is called out in a procedure.

Temporal Contrast Sensitivity: A measure of the sensitivity to contrast (i.e., modulation depth) as a function of time. This can be achieved by presenting stimuli that vary sinusoidally over time; it is like presenting a grating pattern in time instead of space.

Transient Accelerations: Events, linear or rotational, with a duration of less than or equal to 0.5 seconds.

Transmittance: The fraction or percentage of incident electromagnetic radiation such as light at a specified wavelength that passes through a medium.

Unsuited: Wearing the type of clothing that is ordinarily worn in the interior of a spacecraft, especially a habitat, and as might be worn on Earth.

Vehicle/Habitat: A mobile or static spacecraft with a pressurized atmosphere appropriate for sustained, unsuited survival and crew operations. The vehicle is a container, generally composed of multiple elements, used to transport persons or things to/from a location outside of Earth’s atmosphere. (See “habitat” as defined above.) Includes all hardware and equipment within or attached to the pressurized environment.

Visual Accommodation: Defined by the change in optical power of the eye to bring objects at different distances into focus. In young observers, average accommodative power is about 15 diopters but declines to 0 by the age of 60.

Visual Acuity: Defined by the smallest letters that can be identified under standard viewing conditions. An average acuity for young adults is about -0.1 logMAR but declines with age.

Voluntary Consensus Standards: A type of standard developed or adopted by voluntary consensus standards bodies, through the use of a voluntary consensus standards development process defined in the definition of voluntary consensus standards bodies in this section. These bodies often have intellectual property rights (IPR) policies that include provisions requiring that owners of relevant patented technology incorporated into a standard make that intellectual property available to implementers of the standard on a non-discriminatory and royalty-free or reasonable royalty terms (and to bind subsequent owners of standards essential patents to the same terms). A standard that includes patented technology needs to be governed by such policies, which should be easily accessible, set out clear rules governing the disclosure and licensing of the relevant intellectual property, and take into account the interests of all stakeholders, including the IPR holders and those seeking to implement the standard. (Source: OMB Circular No. A-119.)

Voluntary Consensus Standards Body: A type of association, organization, or technical society that plans, develops, establishes, or coordinates voluntary consensus standards using a voluntary consensus standards development process that includes the following attributes or elements:

a. Openness: The procedures or processes used are open to interested parties. Such parties are provided meaningful opportunities to participate in standards development on a non-discriminatory basis. The procedures or processes for participating in standards development and for developing the standard are transparent.
b. Balance: The standards development process should be balanced. Specifically, there should be meaningful involvement from a broad range of parties, with no single interest dominating the decision making.
c. Due process: Due process shall include documented and publicly available policies and procedures, adequate notice of meetings and standards development, sufficient time to review drafts and prepare views and objections, access to views and objections of other participants, and a fair and impartial process for resolving conflicting views.
d. Appeals process: An appeals process shall be available for the impartial handling of procedural appeals.
e. Consensus: Consensus is defined as general agreement, but not necessarily unanimity. During the development of consensus, comments and objections are considered using fair, impartial, open, and transparent processes. (Source: OMB Circular No. A-119).

Warning: Notification of an event that requires immediate action.

Wavefront: The surface joining all adjacent points on a wave that have the same phase, particularly light that travels as an electromagnetic wave.

Wavefront Error: The total optical path difference induced into a wavefront with respect to the wavelength of light, usually referenced to a helium-neon (HeNe) laser wavelength of 632.8 nm. For planar waves, wavefront error occurs when the wavefront is distorted such that an individual wavefront is no longer in phase. This occurs when different parts of the wavefront travel different optical path lengths. In an ideal window, a planar wave will pass through it such that the optical path length at each point on the window is the same, and the wavefront retains the same phase. Wavefront error is aperture dependent. In an imperfect window, the wavefront is distorted, i.e., the phase is not maintained. Wavefront error can be distorted by surface imperfections (the window is not "flat") or by material inhomogeneities (the index of refraction varies across the window).

Window: A non-electronic means for direct through-the-hull viewing using a transparent material; the same as and used interchangeably with window port and window assembly.

Window Assembly: The same as and used interchangeably with window and window port.

Window Cover: An internal non-pressure-containing, transparent sheet or pane, usually of a different material than the windowpanes such as acrylic or other material intended to protect the underlying window pressure and/or protective pane(s) from incidental crew contact. A window cover is normally not an integral part of the window assembly and has the characteristics as specified in section 8.6, Windows, of the HIDH. Non-integral protective panes can be considered temporary, i.e., replaceable after some period of time, after which their optical quality has degraded below the category level for which they were designed. External window protection devices are referred to as shutters.

Window Filter: An internal, non-pressure-containing, transparent sheet or pane, usually of a different material than the windowpanes such as polycarbonate or other material intended to filter non-ionizing radiation hazards to safe levels. A window filter is not considered an integral part of the window assembly. Window filters are easily removed and reinstalled without the use of tools by one crewmember. A window filter may also serve as a window cover.

Window Port: The finished assembly, including the frame structure (includes all gaskets, bolts, spacers, and other such parts) and all window panes that would normally be used at a specific location with any protective panes, permanent coatings, plastic films, or laminates applied or in place; the same as and used interchangeably with window and window assembly.

Window Shade: Usually, an internal, non-pressure-containing, opaque sheet intended to block external light from entering the interior of a crew cabin. A window shade may or may not be an integral part of the window assembly. Non-integral window shades are easily removed and reinstalled without the use of tools by one crewmember. Window shades that are an integral part of the window assembly can also act as window shutters.

Window Shutter: An internally and remotely operable external cover intended to prevent natural and induced environmental degradation, e.g., contamination, erosion, and impacts, of the outboard-most windowpane with open and close indicators that are readable from the remote operating location. Window shutters can be operated through their full range of motion in less than 10 seconds and can serve as window shades.

Workload: The amount of work expected in a unit of time. Physical workload refers to the number of individual physical activities that are conducted simultaneously or in close succession. Similarly, mental or cognitive workload refers to the number of mental operations or activities that are conducted simultaneously or in close succession.

APPENDIX D

REQUIREMENTS COMPLIANCE MATRIX

APPENDIX D

REQUIREMENTS COMPLIANCE MATRIX

D.1 PURPOSE

Due to the complexity and uniqueness of space flight, it is unlikely that all of the requirements in a NASA technical standard will apply. The Requirements Compliance Matrix below contains this NASA Technical Standard's technical authority requirements and may be used by programs and projects to indicate requirements that are applicable or not applicable to help minimize costs. Enter "Yes" in the "Applicable" column if the requirement is applicable to the program or project or "No" if the requirement is not applicable to the program or project. The "Comments" column may be used to provide specific instructions on how to apply the requirement or to specify proposed tailoring.

Table 38—Requirement Compliance Matrix

Section	Rqmt #	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
3.1.1		Full Mission Duration Applicability	In order to protect human health and performance from exposures or conditions that have a cumulative effect, requirements **will** be tailored into program requirements pertaining to the full mission duration (from launch of crew through their landing back on Earth) for each human space flight vehicle or habitat which is used to conduct one or more segments of a multi-segment or multi-vehicle mission, even if their isolated segment would have allowed for higher exposures on its own. Missions may be comprised of consecutive segments that occur in different vehicles, take place in different locations in space with varying distances from Earth, and last for different durations. Many requirements that pertain to cumulative exposures and conditions (such as Permissible Exposure Limits) have been tailored (relaxed) to accommodate short missions occurring in single vehicles. However, for multi-segment or multi-vehicle missions, cumulative exposure over the entire duration of the mission needs to be considered. Exposure in one vehicle that is occupied for a segment of the full mission duration cannot be taken in isolation of the rest of the mission. It is not advisable for each vehicle to maintain its own short duration exposure requirements and expect other vehicles or habitats in the mission to lower their exposure limits to compensate for a higher exposure level in another vehicle. Similarly, a vehicle cannot expect other vehicles within the enterprise to compensate for lack of countermeasures in that vehicle.		
3.2.1	V2 3006	Human-Centered Task Analysis	Each human space flight program or project shall perform a human-centered task analysis to support systems and operations design.		

Section	Rqmt #	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
3.2.2	V2 3102	Human Error Analysis	Each human space flight program or project shall perform a task-based human error analysis (HEA) to support systems and operations design.		
3.2.3	V2 3101	Iterative Developmental Testing	Each human space flight program or project shall perform iterative HITL testing throughout the design and development cycle.		
4.1.1	V2 4102	Functional Anthropometric Accommodation	The system shall ensure the range of potential crewmembers can fit, reach, view, and operate the human systems interfaces by accommodating crewmembers with the anthropometric dimensions and ranges of motion as defined in data sets in Appendix F, Physical Characteristics and Capabilities, Sections F.2 and F.3.		
4.1.2	V2 4103	Body Mass, Volume, and Surface Area Data	The system shall accommodate the body characteristic data for mass, volume, and surface area as defined in Appendix F, Physical Characteristics and Capabilities, Sections F.4, F.5, and F.6.		
4.1.3.1	V2 4104	Crew Operational Loads	The system shall be operable by crew during all phases of flight, including prelaunch, ascent, orbit, entry, and postlanding, with the lowest anticipated strength as defined in Appendix F, Physical Characteristics and Capabilities, Section F.7.		
4.1.3.2	V2 4105	Withstand Crew Loads	The system shall withstand forces imparted by the crew during all phases of flight, including prelaunch, ascent, orbit, entry, and postlanding, as defined in Appendix F, Physical Characteristics and Capabilities, Section F.7 without sustaining damage.		
4.2	V2 4013	Muscle Effects	The effects of muscle endurance and fatigue shall be factored into system design.		
4.3	V2 4015	Aerobic Capacity	The system shall be operable by crewmembers with the aerobic capacity as defined in NASA-STD-3001, Volume 1.		
5.1.1	V2 5001	Visual Capabilities	The system shall accommodate anticipated levels of crew visual capabilities under expected task demands.		
5.1.2	V2 5002	Auditory Perceptual Capabilities	The system shall accommodate anticipated levels of crew auditory perceptual capabilities under expected task demands.		
5.1.3	V2 5003	Sensorimotor Capabilities	The system shall accommodate anticipated levels of crew sensorimotor capabilities under expected task demands.		
5.1.4	V2 5004	Cognitive Capabilities	The system shall accommodate anticipated levels of crew cognitive capabilities under expected tasks demands.		
6.1	V2 6001	Trend Analysis of Environmental Data	The system shall provide environmental monitoring data in formats compatible with performing temporal trend analyses.		
6.2.1.1	V2 6002	Inert Diluent Gas	Cabin atmospheric composition shall contain at least 30% diluent gas (assuming balance oxygen).		
6.2.1.2	V2 6003	O2 Partial Pressure Range for Crew Exposure	The system shall maintain inspired oxygen partial pressure (PIO2) in accordance with Table 1, Inspired Oxygen Partial Pressure Exposure Ranges.		
6.2.1.3	V2 6004	Nominal Vehicle/Habitat Carbon Dioxide Levels	The system shall limit the average one-hour CO2 partial pressure (PICO2) in the habitable volume to no more than 3 mmHg.		
6.2.2.1	V2 6006	Total Pressure Tolerance Range for Indefinite Crew Exposure	The system shall maintain the pressure to which the crew is exposed to between 26.2 kPa $<$ pressure $\leq$ 103 kPa (3.8 psia $<$ pressure $\leq$ 14.9 psia) for indefinite human exposure without measurable impairments to health or performance.		

Section	Rqmt #	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
6.2.2.2	V2 6007	Rate of Pressure Change	For pressure changes >1.0 psi, the rate of change of total internal vehicle pressure shall not exceed 13.5 psi/min.		
6.2.2.3	V2 6150	Barotrauma Prevention	During a commanded pressure change, the system shall pause within 1 psi of the pause command being issued by the unsuited or suited crewmember, with ability to increase or decrease pressure as needed after the pause.		
6.2.2.4	V2 6008	Decompression Sickness (DCS) Risk Identification	Each program shall define mission-unique DCS mitigation strategies to achieve the level of acceptable risk of DCS as defined below within 95% statistical confidence: a. DCS ≤ 15% (includes Type I or isolated cutis marmorata). b. Grade IV venous gas emboli (VGE) ≤ 20%. c. Prevent Type II DCS.		
6.2.2.5	V2 6009	Decompression Sickness Treatment Capability	The system shall provide DCS treatment capability.		
6.2.3	V2 6011	Post Landing Relative Humidity (RH)	For nominal post landing operations, the system shall limit RH to the levels in Table 2, Average Relative Humidity Exposure Limits for Post Landing Operations.		
6.2.4.1	V2 6012	Crew Health Environmental Limits	The system shall maintain levels of cabin humidity and temperature within the boundaries of the Operating Limit as shown in Figure 2, Crew Health Environmental Limits, to protect for crew health during pressurized operations when crew occupies the cabin, excluding suited operations, ascent, entry, landing, and post landing.		
6.2.4.2	V2 6013	Crew Performance Environmental Zone	The system shall be capable of reaching atmospheric humidity and temperatures of nominally occupied habitable volumes within the zone provided in Figure 3, Crew Performance Environmental Zone, during all nominal operations, excluding suited operations, ascent, entry, landing, and post landing.		
6.2.4.3	V2 6151	Temperature Selectability	The system shall provide selectable set points for internal atmosphere temperature in step sizes no greater than 0.5°C increments in the habitable volume.		
6.2.4.4	V2 6152	Temperature Adjustability	The system shall be capable of adjusting temperature in the habitable volume by at least 1°C/hr.		
6.2.4.5	V2 7041	Environmental Control	The system environmental control shall accommodate the increased O2 consumption and additional output of heat, CO2, perspiration droplets, odor, and particulates generated by the crew in an exercise area.		
6.2.5	V2 6017	Atmospheric Control	The system shall allow for local and remote control of atmospheric pressure, humidity, temperature, ventilation, and ppO2.		
6.2.6.1	V2 6020	Atmospheric Data Recording	For each isolatable, habitable compartment, the system shall automatically record pressure, humidity, temperature, ppO2, and ppCO2 data continuously.		
6.2.6.2	V2 6021	Atmospheric Data Displaying	The system shall display real-time values for pressure, humidity, temperature, ppO2, and ppCO2 data to the crew locally and remotely.		
6.2.7.1	V2 6022	Atmospheric Monitoring and Alerting Parameters	The system shall alert the crew locally and remotely when atmospheric parameters, including atmospheric pressure, humidity, temperature, ppO2, and ppCO2 are outside safe limits.		
6.2.7.2	V2 6023	Trace Constituent Monitoring and Alerting	The system shall monitor trace volatile organic compounds (VOCs) in the cabin atmosphere and alert the crew locally and remotely when they are approaching defined limits.		
6.2.7.3	V2 6024	Combustion Monitoring and Alerting	The system shall monitor in real-time the toxic atmospheric components listed in Table 3, Recommended Combustion Product (CP) Monitoring Ranges, that would result from pre-combustion and combustion events in the ranges and with the accuracy and resolution specified in		

Section	Rqmt #	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
			the table, and alert the crew locally and remotely in sufficient time for them to take appropriate action.		
6.2.7.4	V2 6025	Contamination Monitoring and Alerting	The system shall monitor and display atmospheric compound levels that result from contamination events, e.g., toxic release, systems leaks, or externally originated, before, during, and after an event and alert the crew locally and remotely in sufficient time for them to take appropriate action.		
6.2.7.5	V2 6153	Celestial Dust Monitoring and Alerting	The vehicle shall monitor celestial dust and alert the crew locally and remotely when they are approaching defined limits.		
6.2.8.1	V2 6107	Nominal Vehicle/Habitat Atmospheric Ventilation	The system shall maintain a ventilation rate within the internal atmosphere that is sufficient to provide circulation that prevents CO_2 and thermal pockets from forming, except during suited operations, toxic cabin events, or when the crew is not inhabiting the vehicle.		
6.2.8.2	V2 6108	Off-Nominal Vehicle/Habitat Atmospheric Ventilation	The system shall control for ppO_2, $ppCO_2$, and relative humidity during off-nominal operations, such as temporary maintenance activities in areas not in the normal habitable volume.		
6.2.9.1	V2 6050	Atmosphere Contamination Limit	The system shall limit gaseous pollutant accumulation in the habitable atmosphere below individual chemical concentration limits specified in JSC-20584, Spacecraft Maximum Allowable Concentrations for Airborne Contaminants (SMACs).		
6.2.9.2	V2 6052	Particulate Matter	The system shall limit the habitable atmosphere particulate matter concentration for total dust to <3 mg/m^3 with a crew generation rate of 1.33 mg/person-minute, and the respirable fraction of the total dust <2.5 μm (micrometer) in aerodynamic diameter to <1 mg/m^3 with a crew generation rate of 0.006 mg/person-minute.		
6.2.9.3	V2 6053	Lunar Dust Contamination	The system shall limit the levels of lunar dust particles less than 10 μm in size in the habitable atmosphere below a time-weighted average of 0.3 mg/m^3 during intermittent daily exposure periods that may persist up to 6 months in duration.		
6.2.9.4	V2 6059	Microbial Air Contamination	The system shall provide air in the habitable atmosphere that is microbiologically safe for human health and performance.		
6.3.1.1	V2 6026	Potable Water Quality	At the point of crew consumption or contact, the system shall provide aesthetically acceptable potable water that is chemically and microbiologically safe for human use, including drinking, food rehydration, personal hygiene, and medical needs.		
6.3.1.3	V2 6051	Water Contamination Control	The system shall prevent potable and hygiene water supply contamination from microbial, atmospheric (including dust), chemical, and non-potable water sources to ensure that potable and hygiene water are provided.		
6.3.1.4	V2 6046	Water Quality Monitoring	Water quality monitoring capability shall include preflight, in-flight, and post landing sampling and analysis.		
6.3.2	V2 6109	Water Quantity	The system shall provide a minimum water quantity as specified in Table 4, Water Quantities and Temperatures, for the expected needs of each mission, which should be considered mutually independent.		
6.3.3	V2 6110	Water Temperature	The system shall provide the appropriate water temperature as specified in Table 4, Water Quantities and Temperatures, for the expected needs of each mission and task.		
6.3.4.1	V2 6039	Potable Water Dispensing Rate	Water shall be dispensed at a rate that is compatible with the food system.		
6.3.4.2	V2 6040	Potable Water Dispensing Increments	To prevent overflow, water shall be dispensable in specified increments that are compatible with the food preparation instructions and time demands of the allotted meal schedule.		

Section	Rqmt #	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
6.4.1.1	V2 6047	Toxic Hazard Level Three	The system shall use only chemicals that are Toxic Hazard Level Three or below, as defined in JSC-26895, Guidelines for Assessing the Toxic Hazard of Spacecraft Chemicals and Test Materials, in the habitable volume of the spacecraft.		
6.4.1.2	V2 6048	Toxic Hazard Level Four	The system shall prevent Toxic Hazard Level Four chemicals, as defined in JSC-26895, from entering the habitable volume of the spacecraft.		
6.4.1.3	V2 6049	Chemical Decomposition	The system shall use only chemicals that, if released into the habitable volume, do not decompose into hazardous compounds that would threaten health during any phase of operations.		
6.4.2.1	V2 6060	Biological Payloads	Biological payloads, as well as the associated operational procedures and supporting personal protective equipment, shall meet the criteria defined by the JSC Biosafety Review Board guidelines contained in JPR-1800.5, Biosafety Review Board Operations and Requirements.		
6.4.2.2	V2 6061	Environment Cross-Contamination	The system shall provide controls to prevent or otherwise minimize (as appropriate) biological cross-contamination between crew, payloads and vehicles to acceptable levels in accordance with the biosafety levels (BSL) defined in JPR-1800.5, as well between crew, payloads, vehicles and extraterrestrial planetary environments with the extent of application specific to individual planetary bodies and special locations thereon.		
6.4.3	V2 6062	Availability of Environmental Hazards Information	The system shall provide toxicological and environmental hazard information in formats accessible by the crew throughout the mission.		
6.4.4	V2 6063	Contamination Cleanup	The system shall provide a means to remove or isolate released chemical and biological contaminants and to return the environment to a safe condition.		
6.5.1	V2 6064	Sustained Translational Acceleration Limits	The system shall limit the magnitude, direction, and duration of crew exposure to sustained (>0.5 seconds) translational acceleration by staying below the limits in Figure 3—Gx Sustained Translational Acceleration Limits (Seated), Figure 4—Gy Sustained Translational Acceleration Limits (Seated), and Figure 5—Gz Sustained Translational Acceleration Limits (Seated) for seated posture; and Figure 6—Gx Sustained Translational Acceleration Limits (Standing), Figure 7—Gy Sustained Translational Acceleration Limits (Standing), and Figure 8—Gz Sustained Translational Acceleration Limits (Standing) for standing posture.		
6.5.2.1	V2 6065	Rotational Velocity	The system shall limit crew exposure to rotational velocities in yaw, pitch, and roll by staying below the limits specified in Figure 9—Rotational Velocity Limits.		
6.5.2.2	V2 6066	Sustained Rotational Acceleration Due to Cross-Coupled Rotation	The system shall prevent the crew exposure to sustained (>0.5 second) rotational accelerations caused by cross-coupled rotations greater than 2 rad/s^2.		
6.5.2.3	V2 6067	Transient Rotational Acceleration	The system shall limit transient (≤0.5 seconds) rotational accelerations in yaw, pitch, or roll to which the crew is exposed and the limit used appropriately scaled for each crewmember size from the 50th percentile male limits of 2,200 rad/s2 for nominal and 3,800 rad/s2 for off-nominal cases.		
6.5.3	V2 6069	Acceleration Injury Prevention	The system shall mitigate the risk of injury to crewmembers caused by accelerations during dynamic mission phases per Table 5, Acceptable Injury Risk Due to Dynamic Loads.		
6.5.4	V2 6070	Injury Risk Criterion	The system shall limit crew exposure to transient translational acceleration (≤0.5 seconds) by limiting the injury risk criterion (β/beta) to no greater than 1.0 (Low) for seated or standing crew as defined by Dynamic Response (DR) limits in NASA/TM-20205008198 Table 2 “Updated Dynamic Response Limits for Standing”, while crew are restrained as required in NASA/TM-2013-217380REV1 for seated crew, or NASA/TM – 20205008198 for standing crew.		

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6.5.5	V2 6111	Dynamic Mission Phases Monitoring and Analysis	The system shall collect vehicle and crewmember acceleration parameters, specific kinematic responses, and associated metadata, during all dynamic mission phases and suited operations (defined as ascent, abort, entry, descent, landing, postlanding, and EVA operations) to correlate with any injuries incurred by crewmembers.		
6.5.6	V2 6112	Hang Time Limit	The system shall limit crew exposure to suspension trauma conditions to seven minutes or less.		
6.5.7	V2 6113	Crew Limits in Launch Orientation	The time in which crewmembers are on back with feet elevated in a launch configuration shall not exceed 3 hours and 15 minutes, excluding subsequent safing and egress time.		
6.6.1.1	V2 6073	Launch, Entry, and Abort Noise Exposure Limits	During launch, entry, and abort operations, the noise exposure level (not including impulse noise) at the crewmember's ear, calculated over any 24-hour period, shall be limited such that the noise dose (D) is ≤100:(Eq 1.)where:N = the number of noise exposure events during the 24-hour periodCn = the actual duration of the exposure event in minutesTn = the maximum noise exposure duration allowed, based on the specific sound level (Ln) of an exposure event in dBA, calculated using the following equation: (Eq. 2)		
6.6.1.2	V2 6074	Ceiling Limit for Launch and Entry	During launch and entry operations, the system shall limit the combined A-weighted sound levels (not including impulse noise) at the crewmembers' ears to a maximum of 105 dBA.		
6.6.1.3	V2 6075	Ceiling Limit for Launch Abort	During launch abort operations, the system shall limit the combined A-weighted sound levels (not including impulse noise) at the crewmembers' ears to a maximum of 115 dBA.		
6.6.1.4	V2 6076	Launch, Entry, and Abort Impulse Noise Limits	During launch, entry, and abort operations, impulse noise measured at the crewmember's ear location shall be limited to less than 140-dB peak SPL.		
6.6.1.5	V2 6077	Hazardous Noise Limits for All Phases Except Launch, Entry, and Abort	For off-nominal operations, broadcast communications, depressurization valves, and maintenance activities, the A-weighted sound level (excluding impulse noise and alarm signals) shall be less than 85 dBA, regardless of time duration; except in the case of depressurization valves, the noise attenuation effectiveness of hearing protection or communications headsets may not be used to satisfy this requirement.		
6.6.1.6	V2 6115	24-Hour Noise Exposure Limits	The noise exposure level (not including impulse noise) at the crewmember's ear, calculated over any 24-hour period, except during launch, entry, and abort operations, shallshall be limited such that the noise dose (D) is ≤100: (Eq. 3) where: N = the number of noise exposure events during the 24-hour period Cn = the actual duration of the exposure event in minutes Tn = the maximum noise exposure duration allowed, based on the specific sound level (Ln) of an exposure event in dBA, calculated using the following equation: (Eq. 4)		
6.6.1.7	V2 6078	Continuous Noise Limits	In spacecraft work areas, where good voice communications and habitability are required, SPLs of continuous noise (not including impulse noise) shall be limited to the values given by the Noise Criterion (NC)-50 curve in Figure 9, NC Curves, and Table 8, Octave Band SPL Limits for Continuous Noise, dB re 20 µPa (micropascals); hearing protection cannot be used to satisfy this requirement.		

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6.6.1.8	V2 6079	Crew Sleep Continuous Noise Limits	For missions greater than 30 days, SPLs of continuous noise shall be limited to the values given by the NC-40 curve (see Figure 9, NC Curves, and Table 8, Octave Band SPL Limits for Continuous Noise, dB re 20 μPa) in crew quarters and sleep areas. Hearing protection cannot be used to satisfy this requirement.		
6.6.1.9	V2 6080	Intermittent Noise Limits	For hardware items that operate for eight hours or less (generating intermittent noise), the maximum noise emissions (not including impulse noise), measured 0.6 m from the loudest hardware surface, shall be determined according to Table 9, Intermittent Noise A-Weighted SPL and Corresponding Operational Duration Limits for any 24-hour period (measured at 0.6-m distance from the source). Hearing protection cannot be used to satisfy this requirement.		
6.6.1.10	V2 6081	Alarm Maximum Sound Level Limit	The maximum alarm signal A-weighted sound level shall be less than 95 dBA at the operating position of the intended receiver.		
6.6.1.11	V2 6082	Annoyance Noise Limits for Crew Sleep	With the exception of communications and alarms, the system shall limit impulse and intermittent noise levels at the crewmember's head location to 10 dB above background noise levels during crew sleep periods. Hearing protection cannot be used to satisfy this requirement.		
6.6.1.12	V2 6083	Impulse Noise Limit	The system shall limit impulse noise measured at the crewmember's head location to less than 140 dB peak SPL during all mission phases except launch and entry. Hearing protection cannot be used to satisfy this requirement.		
6.6.1.13	V2 6084	Narrow-Band Noise Limits	The maximum SPL of narrow-band noise components and tones shall be limited to at least 10 dB less than the broadband SPL of the octave band that contains the component or tone.		
6.6.1.14	V2 6085	Infrasonic Sound Pressure Limits	Infrasonic SPLs, including frequencies from 1 to 20 Hz but not including impulse noise, shall be limited to less than 150 dB at the crewmember's head location. Hearing protection cannot be used to satisfy this requirement.		
6.6.1.15	V2 6106	Noise Limit for Personal Audio Devices	The system shall limit the maximum A-weighted sound level at the crewmember's ear created by a personal audio device to 115 dBA or less.		
6.6.2.1	V2 6087	Acoustic Monitoring	Broadband and frequency-dependent SPLs shall be monitored and quantified as needed for crew health and safety.		
6.6.2.2	V2 6088	Individual Noise Exposure Monitoring	Noise exposure levels shall be monitored and quantified for each crewmember as needed for crew health and safety.		
6.7.1.1	V2 6089	Vibration during Preflight	The system shall limit vibration to the crew such that the frequency-weighted acceleration between 0.1 to 0.5 Hz in each of the X, Y, and Z axes is less than 0.05 g (0.5 m/s2) root mean square (RMS) for each 10-minute interval during prelaunch (when calculated in accordance with ISO 2631-1:1997(E), Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 1: General requirements, Annex D, Equation D-1).		
6.7.1.2	V2 6090	Vibration Exposures during Dynamic Phases of Flight	The system shall limit vibration during dynamic phases of flight to the crew such that the vectorial sum of the X, Y, and Z accelerations between 0.5 and 80 Hz, calculated in 1-s intervals and weighted in accordance with ISO 2631-1:1997(E), is less than or equal to the levels plotted for the accumulated durations in Table 10, Frequency-Weighted Vibration Limits by Exposure Time during Dynamic Phases of Flight, and Figure 12, Frequency-Weighted Vibration Limits by Exposure Time during Dynamic Phases of Flight.		
6.7.1.3	V2 6091	Long-Duration Vibration Exposure Limits for Health during Non-Sleep Phases of Mission	The system shall limit vibration to the crew such that the vectorial sum of the X, Y, and Z frequency-weighted accelerations, as computed according to ISO 2631-1:1997(E), do not exceed the minimum health guidance caution zone level defined by Figure B.1 in ISO 2631-1:1997(E), Annex B.		

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6.7.1.4	V2 6092	Vibration Exposure Limits during Sleep	The system shall limit vibration to the crew such that the acceleration between 1.0 and 80 Hz in each of the X, Y, and Z axes, weighted in accordance with ISO 20283-5, Mechanical vibration—Measurement of vibration on ships; Part 5 - Guidelines for the measurement, evaluation and reporting of vibration with regard to habitability on passenger and merchant ships, Annex A, is less than 0.01 g (0.1 m/s2) RMS for each two-minute interval during the crew sleep period.		
6.7.1.5	V2 6093	Vibration Limits for Performance	Crew tasks shall be evaluated for performance (e.g., motor control accuracy and precision, vision/readability, speech clarity, attentional focus) for all expected (nominal and off-nominal) vibration levels.		
6.7.2	V2 6094	Hand Vibration	The system, including tools, equipment, and processes, shall limit vibration to the crewmembers' hands such that the accelerations, as computed according to ANSI/ASA S2.70-2006, Guide for the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hand, do not exceed the Daily Exposure Action Value defined by ANSI/ASA S2.70-2006, Annex A, Figure A.1.		
6.8.1.1	V2 6095	Ionizing Radiation Protection Limit	The program shall set system design requirements to prevent potential crewmembers from exceeding PELs as set forth in NASA-STD-3001, Volume 1.		
6.8.1.2	V2 6097	Crew Radiation Exposure Limits	The program/project shall design systems using the ALARA principle to limit crew radiation exposure.		
6.8.1.3	V2 6098	Radiation Environments	The program shall specify the radiation environments to be used in verifying the radiation design requirements.		
6.8.1.4	V2 6099	Space Weather Monitoring	The program shall set requirements specifying appropriate capabilities to be provided for real-time monitoring of space weather (solar particle events (SPE), galactic cosmic rays (GCR), etc.) for characterization of the radiation environment and operational response by ground personnel and the crew.		
6.8.1.5	V2 6100	Ionizing Radiation Alerting	The system shall include a method to alert the crew locally and remotely when radiation levels are expected to exceed acceptable levels.		
6.8.1.6	V2 6101	Ionizing Radiation Dose Monitoring	To characterize and manage radiation exposures, the program shall provide methods for monitoring personal dose and dose equivalent exposure, ambient monitoring of particle fluence as a function of direction, energy, and elemental charge and monitoring of ambient dose and ambient dose equivalent.		
6.8.2.1	V2 6102	RF Non-Ionizing Radiation Exposure Limits	The system shall maintain the crew exposure to RF electromagnetic fields to or below the limits stated in Table 11, Maximum Permissible Exposure (MPE) to RF Electromagnetic Fields, and shown graphically in Figure 10, RF Electromagnetic Field Exposure Limits.		
6.8.2.2	V2 6103	Laser Exposure Limits	The system shall maintain the crew ocular and dermal exposure to laser systems and the ocular exposure of the uncontrolled ground population to space lasers to or below the limits specified in ANSI Z136.1, 2014, American National Standard for Safe Use of Lasers, Table 5 (ocular) and Table 7 (dermal) without Personal Protective Equipment.		
6.8.2.3	V2 6104	Natural Sunlight Exposure Limits	The system shall maintain the crew exposure to natural sunlight for spectral radiance or irradiance (as applicable) within wavelengths between 180 nm and 3000 nm, as noted in Table 12, Natural Sunlight Exposure Limits for Different Damage Mechanisms.		
6.8.2.5	V2 6117	Artificial Light Exposure Limits for Ultraviolet (UV) Sources	The system shall fully contain UV sources to prevent crew exposure.		
7.1.1.1	V2 7001	Food Quality	The food system shall provide the capability to maintain food safety and nutrition during all phases of the mission.		
7.1.1.2	V2 7002	Food Acceptability	The system shall provide food that is acceptable to the crew for the duration of the mission.		

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7.1.1.3	V2 7003	Food Caloric Content	The system shall provide each crewmember with an average of 12,698 kJ (3,035 kcal) per day, else an average energy requirement value is determined using Table 13, EER Equations and applying an activity factor appropriate to the mission gravity and planned level of physical activity.		
7.1.1.4	V2 7004	EVA Food Caloric Content	For crewmembers performing EVA operations, the food system shall provide an additional 837 kJ (200 kcal) per EVA hour above nominal metabolic intake as defined by [V2 7003] Food Caloric Content of this NASA Technical Standard.		
7.1.1.5	V2 7100	Food Nutrient Composition	The system shall provide a food system with a diet including the nutrient composition that is indicated in the Dietary Reference Intake (DRI) values as recommended by the National Institutes of Health, with the exception of those adjusted for space flight as noted in Table 14, Nutrient Guidelines for Space flight.		
7.1.1.6	V2 7007	Food and Production Area Microorganism Levels	Microorganism levels in the food and production area shall not exceed those specified in Table 15, Food Microorganism Levels.		
7.1.2.1	V2 7008	Food Preparation	The system shall provide the capability for preparation, consumption, and stowage of food.		
7.1.2.2	V2 7009	Food Preparation and Cleanup	The food system shall allow the crew to unstow supplies, prepare meals, and clean up for all crewmembers within the allotted meal schedule.		
7.1.2.3	V2 7010	Food Contamination Control	The food storage, preparation, and consumption areas shall be designed and located to protect against cross-contamination between food and the environment.		
7.1.2.4	V2 7011	Food and Beverage Heating	The system shall provide the capability to heat food and beverages to a temperature appropriate for the given item.		
7.1.2.5	V2 7012	Dining Accommodations	Crewmembers shall have the capability to dine together.		
7.1.2.6	V2 7014	Food Spill Control	The system shall provide the ability to contain and remove food particles and spills.		
7.1.2.7	V2 7015	Food System Cleaning and Sanitizing	The system shall provide methods for cleaning and sanitizing food facilities, equipment, and work areas.		
7.2.1	V2 7016	Personal Hygiene Capability	Personal hygiene items shall be provided for each crewmember, along with corresponding system capabilities for oral hygiene, personal grooming, and body cleansing.		
7.2.2	V2 7017	Body Cleansing Privacy	The system shall provide for privacy during personal hygiene activities.		
7.2.3	V2 7019	Hygiene Maintainability	The system shall provide an environmentally compatible sanitization method for personal hygiene facilities and equipment.		
7.3.1.1	V2 7020	Body Waste Management Capability	The system shall provide the capability for collection, containment, and disposal of body waste for both males and females.		
7.3.1.2	V2 7021	Body Waste Management System Location	The body waste management system shall be isolated from the food preparation and consumption areas for aesthetic and hygienic purposes.		
7.3.1.3	V2 7022	Body Waste Management Privacy	The system shall provide privacy during use of the body waste management system.		
7.3.1.4	V2 7023	Body Waste Management Provision	Body waste management supplies shall be provided for each crewmember and be located within reach of crewmembers using the waste management system.		
7.3.1.5	V2 7024	Body Waste Accommodation	The body waste management system shall allow a crewmember to urinate and defecate simultaneously without completely removing lower clothing.		
7.3.1.6	V2 7025	Body Waste Containment	The system shall prevent the release of body waste from the waste management system.		
7.3.1.7	V2 7026	Body Waste Odor	The system shall provide odor control for the waste management system.		
7.3.1.8	V2 7027	Body Waste Trash Receptacle Accessibility	Body waste management trash collection shall be accessible to and within reach of crewmembers using the waste management system.		

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7.3.1.9	V2 7029	Body Waste Management Maintenance	All body waste management facilities and equipment shall be capable of being cleaned, sanitized, and maintained.		
7.3.1.10	V2 7101	Body Waste Isolation	For missions greater than 30 days, the system shall provide separate dedicated volumes for body waste management and personal hygiene.		
7.3.2.1	V2 7102	Body Waste Quantities	The human body waste management system shall be capable of collecting and containing the various human body waste as specified in Table 16, Body Waste Quantities, for the expected needs of each mission and task.		
7.3.2.2	V2 7085	Fecal and Urine Elimination Concurrence	The body waste management system shall be capable of collecting and containing all waste during simultaneous defecation and urination.		
7.3.2.3	V2 7035	Urine per Crewmember	The human body waste management system shall be capable of collecting and containing urine for either processing or disposal of an average total urine output volume of $V_u = 3 + 2.5t$ liters per crewmember, where t is the mission length in days.		
7.4.1	V2 7038	Physiological Countermeasures Capability	The system shall provide countermeasures to meet crew bone, muscle, sensorimotor, thermoregulation, and aerobic/cardiovascular requirements defined in NASA-STD-3001, Volume 1.		
7.4.2	V2 7040	Physiological Countermeasure Operations	The physiological countermeasure system design shall allow the crew to unstow supplies, perform operations, and stow items within the allotted countermeasure schedule.		
7.4.3	V2 7042	Orthostatic Intolerance Countermeasures	The system shall provide countermeasures to mitigate the effects of orthostatic intolerance when transitioning from weightlessness to gravity environments and during Gz (head-to-foot) vehicle accelerations defined in the sustained acceleration limits.		
7.5.1	V2 7043	Medical Capability	A medical system shall be provided to the crew to meet the medical requirements of NASA-STD-3001, Volume 1.		
7.5.2	V2 7045	Medical Equipment Usability	Medical equipment shall be usable by non-physician crewmembers in the event that a physician crewmember is not present or is the one who requires medical treatment.		
7.5.3	V2 7046	Medical Treatment Restraints	The capability shall exist to position and restrain a patient, care provider, and equipment during treatment.		
7.5.4	V2 7049	Deceased Crew	Each human space flight program shall provide the capability to handle deceased crewmembers.		
7.6.1.1	V2 7050	Stowage Provisions	The system shall provide for the stowage of hardware and supplies, to include location, restraint, and protection for these items.		
7.6.1.2	V2 7051	Personal Stowage	The system shall provide a stowage location for personal items and clothing.		
7.6.1.3	V2 7052	Stowage Location	All relocatable items, e.g., food, EVA suits, and spare parts, shall have a dedicated stowage location.		
7.6.1.4	V2 7053	Stowage Interference	The system shall provide defined stowage locations that do not interfere with crew operations.		
7.6.1.5	V2 7054	Stowage Restraints	The system shall provide the capability to restrain hardware, supplies, and crew personal items that are removed or deployed for use as defined by crew task analysis.		
7.6.2.1	V2 7055	Priority of Stowage Accessibility	Stowage items shall be accessible in accordance with their use, with the easiest accessibility for mission-critical and most frequently used items.		
7.6.2.2	V2 7056	Stowage Operation without Tools	Stowage containers and restraints shall be operable without the use of tools.		
7.6.2.3	V2 7057	Stowage Access while Suited	The stowage system shall be accessible by a suited crewmember.		
7.6.3	V2 7058	Identification System	The stowage identification system shall be compatible with the inventory management system.		

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7.7.1	V2 7059	Inventory Tracking	The system shall provide an inventory management system to track the locations and quantities of items (including hazardous trash) throughout the mission.		
7.7.2	V2 7060	Inventory Operations	The system shall be designed to allow inventory management functions to be completed within the allotted schedule.		
7.7.3	V2 7061	Nomenclature Consistency	The nomenclature used to refer to the items tracked by the inventory management system shall be consistent with procedures and labels.		
7.7.4	V2 7062	Unique Item Identification	Items that need to be uniquely identified shall have a unique name.		
7.7.5	V2 7063	Interchangeable Item Nomenclature	Items within the inventory management system that are identical and interchangeable shall have identical nomenclature.		
7.8.1.1	V2 7064	Trash Accommodation	The system shall provide a trash management system to contain, mitigate odors, prevent release, and dispose of all expected trash.		
7.8.1.2	V2 7065	Trash Volume Allocation	Trash stowage volumes shall be allocated for each mission.		
7.8.1.3	V2 7066	Trash Stowage Interference	The system shall provide defined trash stowage that does not interfere with crew operations.		
7.8.2	V2 7069	Labeling of Hazardous Waste	The hazard response level (HRL) of all liquids, particles, gases and gels shall be labeled on the outermost containment barrier in location(s) visible to crew.		
7.9.1	V2 7070	Sleep Accommodation	The system shall provide volume, restraint, accommodations, environmental control (e.g., vibration, lighting, noise, and temperature), and degree of privacy for sleep for each crewmember, to support overall crew health and performance.		
7.9.2	V2 7071	Behavioral Health and Privacy	For long duration missions (>30 days), individual privacy facilities shall be provided.		
7.9.3	V2 7073	Partial-g Sleeping	The system shall provide for horizontal sleep surface areas for partial-g and 1-g environments.		
7.10.1	V2 7074	Clothing Quantity	Clean, durable clothing shall be provided in quantities sufficient to meet crew needs.		
7.10.2	V2 7075	Clothing Exclusive Use	Clothing shall be provided for each individual crewmember’s exclusive use.		
7.10.3	V2 7076	Clothing Safety and Comfort	Clothing shall be comfortable in fit and composition, for the environment, e.g., temperature and humidity, in which it will be worn.		
7.11.1	V2 7079	Accessibility for Cleaning	The system shall provide sufficient volume to access areas that need to be cleaned and perform housekeeping duties.		
7.11.2	V2 7080	Particulate Control	The system shall be designed for access, inspection, and removal of particulates that can be present before launch or that can result from mission operations.		
7.11.3	V2 7081	Microbial Surface Contamination	The system shall provide surfaces that are microbiologically safe for human contact.		
7.11.4	V2 7082	Surface Material Cleaning	The system shall contain surface materials that can be easily cleaned and sanitized using planned cleaning methods.		
7.11.5	V2 7083	Cleaning Materials	The system shall provide cleaning materials that are effective, safe for human use, and compatible with system water reclamation, air revitalization, waste management systems, and spacesuits.		
7.11.6	V2 6058	Condensation Limitation	The system shall prevent condensation persistence on surfaces within the vehicle.		
7.12	V2 7084	Recreational Capabilities	The system shall provide individual and team-oriented recreational capabilities for the crew to maintain behavioral and psychological health.		
8.1.1	V2 8001	Volume Allocation	The system shall provide the defined habitable volume and layout to physically accommodate crew operations and living.		
8.1.2	V2 8005	Functional Arrangement	Habitability functions shall be located based on the use of common equipment, interferences, and the sequence and compatibility of operations.		

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8.1.3	V2 8006	Interference	The system shall separate functional areas whose functions would detrimentally interfere with each other.		
8.2.1	V2 8007	Spatial and Interface Orientation	The system shall have consistent spatial and interface orientations relative to a defined vertical orientation.		
8.2.2	V2 8010	Location Identifiers	A standard location coding system shall be provided to uniquely identify each predefined location within the system.		
8.2.3	V2 8011	Location Aids	The system shall provide aids to assist crewmembers in locating items or places within the system and orienting themselves in relation to those items or places.		
8.3.1	V2 8013	Intravehicular Translation Paths	The system shall provide intravehicular activity (IVA) translation paths that allow for safe and unencumbered movement of suited and unsuited crew and equipment.		
8.3.2	V2 8014	Emergency Escape Paths	The system shall provide unimpeded and visible emergency escape routes commensurate with the hazard analyses and response concepts.		
8.3.3	V2 8020	Assisted Ingress and Egress Translation Path	The system shall provide translation paths that accommodate the ingress and egress of a crewmember assisted by another crewmember.		
8.3.4	V2 11005	EVA Translation Path Hazard Avoidance	EVA translation paths shall be free from hazards.		
8.4.1.1	V2 8022	Hatches, Hatch Covers, and Door Operation without Tools	Hatches, hatch covers, and doors shall be operable on either side by a single crewmember without the use of tools in expected gravity conditions, orientations, suit configurations, and operational configurations.		
8.4.1.2	V2 8023	Unlatching Hatch Covers	Hatch covers shall require two distinct and sequential operations to unlatch.		
8.4.1.3	V2 8024	Hatch Cover and Door Operating Times	For nominal operations, hatch covers and doors shall be operable by a single crewmember in no more than 60 seconds, from both sides of the hatch.		
8.4.1.4	V2 8025	Hatch Cover and Door Operating Force	The forces required to operate each crew interface for the hatch covers and doors shall be within the crewmember strength defined by requirement [V2 4104] Crew Operational Loads for the worst-case pressure differential and anticipated encumbering equipment and clothing.		
8.4.2.1	V2 8027	Hatch Size and Shape	Hatches and doorways shall be sized and shaped to accommodate all planned translations, including unrestricted passage of a suited crewmember and crewmembers carrying cargo or equipment.		
8.4.2.2	V2 8028	Pressure Equalization across the Hatch	Each side of each hatch shall have manual pressure equalization capability with its opposite side, achievable from that side of the pressure hatch by a suited or unsuited crewmember.		
8.4.2.3	V2 8029	Visibility across the Hatch	The system shall provide a window for direct, non-electronic visual observation of the environment on the opposite side of the hatch.		
8.4.3.1	V2 8030	Hatch Cover and Door Interference	When opened, hatch covers and doors shall allow for unrestricted flow of traffic.		
8.4.3.2	V2 8031	Hatch Cover Closure and Latching Status Indication	The pressure hatch covers shall indicate closure and latching status on both sides of the hatch.		
8.4.3.3	V2 8032	Hatch Cover Pressure Indication	Pressure hatch covers shall indicate, viewable from both sides of the hatch, pressure differential across the hatch.		
8.4.4	V2 8101	No Drag-Throughs	Hatchways shall be clear of drag-throughs.		
8.4.5	V2 8032	Hatch Pressure Indication	Pressure hatches shall indicate, on both sides of the hatch, pressure differential across the hatch.		
8.5.1	V2 8033	Restraints for Crew Tasks	The system shall provide restraints for expected crew operations.		
8.5.2	V2 8038	Restraint and Mobility Aid Standardization	Restraints and mobility aids shall be standardized, clearly distinguishable, and located to aid crewmembers in starting or stopping movement, changing direction or speed, or translating equipment.		

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8.5.3	V2 8040	Mobility Aid for Assisted Ingress and Egress	Mobility aids shall be provided for the assisted ingress and egress of suited or unsuited crewmembers.		
8.5.4	V2 8041	Unassisted Ingress, Egress, and Escape Mobility Aids	Mobility aids shall be provided for ingress, egress, and escape of crewmembers without assistance from other crew or ground personnel.		
8.5.5	V2 8042	Mobility Aid Provision	Mobility aids shall be provided to support all expected suited and unsuited tasks.		
8.5.6	V2 8102	Human Transport Vehicle Restraint Provision	The human transport vehicle, when operating in fractional (lunar or planetary) gravity, shall provide a restraint for each person inside the vehicle.		
8.6.1	V2 8043	Window Provisioning	The system shall provide windows with unobstructed fields of view for expected crew operations.		
8.6.2	V2 8045	Window Optical Properties	System windows shall have optical properties commensurate with crew task needs.		
8.6.3	V2 8049	Window Light Blocking	Each system window shall provide a means to prevent external light from entering the crew compartment, such that the interior light level can be reduced to 2.0 lux at 0.5 m (20 in) from each window.		
8.6.4	V2 8050	Window Accessory Replacement/Operation without Tools	System window accessories designed for routine use shall be operable by one crewmember and be removable or replaceable without the use of tools.		
8.7.1	V2 8051	Illumination Levels	The system shall provide illumination levels to support the range of expected crew tasks.		
8.7.2	V2 8052	Exterior Lighting	The system shall provide exterior lighting to aid the crew in assembly, maintenance, navigation, rendezvous and docking, ingress and egress, EVA operations, and external task operations.		
8.7.3	V2 8053	Emergency Lighting	The system shall provide emergency lighting for crew egress and/or operational recovery in the event of a general power failure.		
8.7.4	V2 8059	Lighting Chromaticity	Interior and exterior lighting intended for operational environments requiring human/camera color vision shall have a chromaticity that falls within the chromaticity gamut for white light for the Correlated Color Temperature (CCT) range of 2700 K to 6500 K as defined by ANSI C78-377, Electric Lamps—Specifications for the Chromaticity of Solid State Lighting Products.		
8.7.5	V2 8060	Lighting Color Accuracy	Interior and exterior lighting intended for human operational environments requiring photopic vision accuracy shall have a score of 90 ±10 on a color fidelity metric that is appropriate for the utilized lighting technology, as designated by the Color Fidelity Metric (Rf) defined by IES TM-30, Method for Evaluating Light Sources Color Rendition methodology.		
8.7.6	V2 8055	Physiological Effects of Light (Circadian Entrainment)	The system shall provide the levels of light to support the physiological effects of light in accordance with Table 17, Physiological Lighting Specifications.		
8.7.7	V2 8056	Lighting Controls	Lighting systems shall have on-off controls.		
8.7.8	V2 8057	Lighting Adjustability	Interior lights shall be adjustable (dimmable) from their maximum output level to their minimum luminance.		
8.7.9	V2 8058	Glare Prevention	Both direct and indirect glare that causes discomfort to humans or impairs their vision shall be prevented.		
9.1.1	V2 9001	Crew Interface Commonality	Hardware and equipment performing similar functions shall have commonality of crew interfaces.		
9.1.2	V2 9002	Differentiation	Hardware and equipment that have the same or similar form but different functions shall be readily identifiable, distinguishable, and not be physically interchangeable.		
9.1.3	V2 9003	Routine Operation	Worksites shall be designed to provide rapid access to needed tools and equipment for routine/nominal operations.		

Section	Rqmt #	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
9.2	V2 9004	Training Minimization	Hardware and equipment with which crew interact shall minimize the time required for training.		
9.3.1.1	V2 9101	Design for Crew Safety	The system shall be designed to minimize physical hazards to the crew.		
9.3.1.2	V2 9005	Mechanical Hazard	Systems, hardware, and equipment shall protect the crew from moving parts that may cause injury to the crew.		
9.3.1.3	V2 9006	Entrapment	Systems, hardware, and equipment shall protect the crew from entrapment (tangles, snags, catches, etc.).		
9.3.1.4	V2 9007	Potential Energy	Hardware and equipment shall not release stored potential energy in a manner that causes injury to the crew.		
9.3.1.5	V2 9008	Protection from Projectiles and Structural Collapse	Hardware mounting and habitat enclosures shall be configured such that the crew is protected from projectiles and structural collapse in the event of sudden changes in acceleration or collisions.		
9.3.1.6	V2 9009	Sharp Corners and Edges – Fixed	Corners and edges of fixed and handheld equipment to which the bare skin of the crew could be exposed shall be rounded as specified in Table 16, Corners and Edges.		
9.3.1.7	V2 9010	Protection from Functionally Sharp Items	Functionally sharp items shall be prevented from causing injury to the crew or damage to equipment when not in use.		
9.3.1.8	V2 9011	Sharp Corners and Edges - Loose	Corners and edges of loose equipment to which the crew could be exposed shall be rounded to radii no less than those given in Table 17, Loose Equipment Corners and Edges.		
9.3.1.9	V2 9012	Burrs	Exposed surfaces shall be free of burrs.		
9.3.1.10	V2 9013	Pinch Points	Pinch points shall be covered or otherwise prevented from causing injury to the crew.		
9.3.1.11	V2 9016	Equipment Handling	All items designed to be carried or removed and replaced shall have a means for grasping, handling, and carrying while wearing the most encumbering equipment and clothing anticipated.		
9.3.1.2	V2 9102	Skin/Tissue Damage Temperature Limits	Any surface to which the bare skin of the crew is exposed shall not cause skin temperature to exceed the catastrophic injury limits in Table 19, Skin Catastrophic Temperature Injury Limits.		
9.3.1.3	V2 9103	Pain/Non- Disabling Injury Skin Temperature Limits	Any surface to which the bare skin of the crew is exposed shall not cause skin temperature to exceed the critical injury limits in Table 20—Critical Range/Limits, Pain/Non- disabling injury/possibly resulting in illness.		
9.3.3.1	V2 9017	Power Interruption	The system shall provide the crew with capability to control the power to an electrical circuit.		
9.3.3.2	V2 9018	Energized Status	The system shall provide and display the de-energized status (interruption of electrical power) of a circuit to the crew and within their fields of regard.		
9.3.3.3	V2 9019	Nominal Physiological Electrical Current Limits	Under nominal situations (routine human contacts to conductive housing), the program shall limit electrical current through the crewmember to ≤ (less than or equal to) 0.4 mA for Direct Current (DC) and ≤ (less than or equal to) 0.2 mA peak for Alternating Current (AC).		
9.3.3.4.1	V2 9020	Catastrophic Physiological Electrical Current Limits for all Circumstances	The program shall limit the electrical current through the crewmember to ≤ (less than or equal to) 40mA for DC and ≤ (less than or equal to) 8 mA peak for AC to avoid catastrophic physiological effects to the crewmember.		
9.3.3.4.2	V2 9021	Catastrophic Physiological Electrical Current Limits for Startle Reaction	During critical operations where a startle reaction is possible, the program shall limit electrical current through the crewmember to ≤ (less than or equal to) 2 mA for DC and ≤ (less than or equal to) 0.5 mA for AC to avoid potentially catastrophic conditions.		
9.3.3.5	V2 9022	Body Impedance for Voltage Calculations Utilizing Electrical Current Thresholds	The program/project shall use the 5th percentile values for the appropriate conditions (wet/dry, AC/DC, voltage level, large/small contact area) from IEC 60479-1, Effects of current on human beings and livestock - Part 1: General aspects, to determine the appropriate body impedance to calculate the voltage associated with any current limit analysis.		

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9.3.3.6	V2 9023	Leakage Currents – Equipment Designed for Human Contact	For equipment such as bioinstrumentation and medical devices, that are specifically designed to contact the human body, electrical leakage currents caused by contact with exposed surfaces shall be kept below the levels specified in Table 21, Leakage Currents-Medical and Bioinstrumentation Equipment.		
9.3.4.1	V2 9024	Fluid/Gas Release	Hardware and equipment shall not release stored fluids or gases in a manner that causes injury to the crew.		
9.3.4.2	V2 9025	Fluid/Gas Isolation	The system shall provide for the isolation or shutoff of fluids in hardware and equipment.		
9.3.4.3	V2 9026	Fluid/Gas Containment	The system shall provide for containment and disposal of fluids that might be released during operation or maintenance.		
9.4.1	V2 9027	Protection	Systems, hardware, and equipment shall be protected from and be capable of withstanding forces imposed intentionally or unintentionally by the crew.		
9.4.2	V2 9028	Isolation of Crew from Spacecraft Equipment	Protective provisions, e.g., close-out panels, shall be provided to isolate and separate equipment from the crew within the habitable volume.		
9.5.1	V2 9029	Hardware and Equipment Mounting and Installation	System hardware and equipment shall be designed so that it cannot be mounted or installed improperly.		
9.5.2.1	V2 9030	Connector Spacing	The spacing between connectors shall permit mating and demating by crewmembers wearing expected clothing.		
9.5.2.2	V2 9031	Connector Actuation without Tools	Connectors shall be operable without tools for mating and demating while wearing the most encumbering equipment and clothing anticipated.		
9.5.2.3	V2 9032	Incorrect Mating, Demating Prevention	Cable, gas and fluid lines, and electrical umbilical connectors shall prevent potential mismating and damage associated with mating or demating tasks.		
9.5.2.4	V2 9033	Mating, Demating Hazards	The system shall not subject personnel and equipment to hazards, including spills, electrical shocks, and the release of stored energy, during mating or demating.		
9.6.1	V2 9034	Cable Management	The system shall manage cable, wire, and hose location, protection, routing, and retention to prevent physical interference with crew operations and safety.		
9.6.2	V2 9035	Cable Identification	All maintainable cables, wires, and hoses shall be uniquely identified.		
9.7.1.1	V2 9036	Design for Maintenance	The system shall provide the means necessary for the crew to safely and efficiently perform routine service, maintenance, and anticipated unscheduled maintenance activities while wearing the most encumbering equipment and clothing anticipated.		
9.7.1.2	V2 9037	Commercial Off-the-Shelf (COTS) Equipment Maintenance	Maintenance for commercial off-the-shelf equipment shall be suitable to the space flight environment.		
9.7.1.3	V2 9038	In-Flight Tool Set	Each program shall establish a set of in-flight tools necessary to maintain or reconfigure the space flight system. Also, tools are to be usable by the full range of crew sizes and strengths wearing any protective equipment (EVA suits, protective eyewear, gloves, etc.).		
9.7.2.1	V2 9039	Maintenance Time	Planned maintenance for systems and associated hardware and equipment shall be capable of being performed within the allotted crew schedule while wearing the most encumbering equipment and clothing anticipated.		
9.7.2.2	V2 9042	Captive Fasteners	Fasteners used by the crew during maintenance shall be captive.		
9.7.2.3	V2 9043	Minimum Number of Fasteners - Item	For items that may be serviceable by the crew, the number of fasteners used shall be the minimum required to meet structural engineering design practices.		
9.7.2.4	V2 9044	Minimum Variety of Fasteners - System	The system shall be serviceable with a common set of fasteners that meet structural engineering design practices.		

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9.7.3.1	V2 9045	Maintenance Item Location	The system shall locate maintenance items so that the maintenance task does not require the removal or disabling of other systems or components.		
9.7.3.2	V2 9046	Check and Service Point Accessibility	Check points and service points for systems, hardware, and equipment shall be directly accessible while wearing the most encumbering equipment and clothing anticipated.		
9.7.3.3	V2 9047	Maintenance Accommodation	Physical work access envelopes shall accommodate the crew, required tools, and any protective equipment needed to perform maintenance.		
9.7.3.4	V2 9048	Visual Access for Maintenance	Maintenance tasks that require visual feedback shall be directly visible during task performance while wearing the most encumbering equipment and clothing anticipated.		
9.7.3.5	V2 9050	Tool Clearance	The system shall provide tool clearances for tool installation and actuation for all tool interfaces during in-flight maintenance.		
9.7.4.1	V2 9051	Fault Detection	The system shall provide rapid and positive fault detection and isolation of defective items.		
9.7.4.2	V2 9052	Failure Notification	The system shall alert the crew when critical equipment has failed or is not operating within tolerance limits.		
9.8.1.1.1	V2 9053	Protective Equipment	Protective equipment shall be provided to protect the crew from expected hazards.		
9.8.1.1.2	V2 9054	Protective Equipment Use	Protective equipment shall not interfere with the crew’s ability to conduct the nominal or contingency operations that the crew is expected to perform while employing the protective equipment, including communication among crewmembers and with ground personnel.		
9.8.1.1.3	V2 9055	Protective Equipment Automation	Automation of protective equipment shall be provided when the crew cannot perform assigned tasks.		
9.8.1.2.1	V2 9056	Use of Hearing Protection	The system shall meet SPL limits of section 6.6.2, Acoustic and Noise Monitoring Limits, in this NASA Technical Standard, except where otherwise specified in this NASA Technical Standard, without requiring the use of personal hearing protection.		
9.8.1.2.2	V2 9057	Hearing Protection Provision	Appropriate personal hearing protection shall be provided to the crew during all mission phases for contingency or personal preference.		
9.8.1.2.3	V2 9058	Hearing Protection Interference	The system shall be designed so that hearing protection does not inhibit voice communication, monitoring of systems, and detection of alerts.		
9.8.2.1	V2 9059	Fire Detecting, Warning, and Extinguishing	A fire protection system comprised of detecting, warning, and extinguishing devices shall be provided to all spacecraft volumes during all mission phases without creating a hazardous environment.		
9.8.2.2	V2 9060	Fire Protection System Health and Status	The fire protection system health and status data shall be provided to the crew and other mission systems.		
9.8.2.3	V2 9061	Fire Protection System Failure Alerting	The crew shall be alerted to failures of the fire protection system.		
9.8.2.4	V2 9062	Fire Protection System Activation	The fire protection system shall be capable of being manually activated and deactivated.		
9.8.2.5	V2 9063	Portable Fire Extinguishers	A fire protection system shall include manually operated portable fire extinguishers usable while wearing the most encumbering equipment and clothing anticipated.		
9.8.3	V2 9064	Emergency Equipment Accessibility	Emergency equipment shall be clearly identified, accessible, and useable to complete emergency response in the time required during all mission phases where the corresponding emergency may occur while wearing the most encumbering equipment and clothing anticipated.		
10.1.1.1	V2 10001	Crew Interface Usability	The system shall provide crew interfaces that result in a NASA-modified System Usability Scale (SUS) score of 85 or higher.		

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10.1.1.2	V2 10002	Design-Induced Error	The system shall provide crew interfaces that result in the maximum observed error rates listed in Table 29, Maximum Observed Design-Induced Error Rates.		
10.1.1.3	V2 10003	Crew Interface Operability	The system shall provide interfaces that enable crewmembers to successfully perform tasks within the appropriate timeframe and degree of accuracy.		
10.1.1.4	V2 5007	Cognitive Workload	The system shall provide crew interfaces that result in Bedford Workload Scale ratings of 3 or less for nominal tasks and 6 or less for off-nominal tasks.		
10.1.1.5	V2 10200	Physical Workload	The system shall provide crew interfaces that result in a Borg-CR10 rating of perceived exertion (RPE) of 4 (somewhat strong) or less.		
10.1.1.6	V2 5006	Situation Awareness (SA)	Systems shall provide the Situation Awareness (SA) necessary for efficient and effective task performance and provide the means to recover SA, if lost, for anticipated levels of crewmember capability and anticipated levels of task demands.		
10.1.2	V2 10004	Controllability and Maneuverability	The spacecraft shall exhibit Level 1 handling qualities (Handling Qualities Rating (HQR) 1, 2 and 3), as defined by the Cooper-Harper Rating Scale, during manual control of the spacecraft's flight path and attitude when manual control is the primary control mode or automated control is non-operational.		
10.1.3.1	V2 10005	Crew Interfaces Standardization	Crew interfaces shall be standardized throughout a system.		
10.1.3.2	V2 10006	Operations Nomenclature Standardization	Operational nomenclature shall be standardized throughout a system.		
10.1.3.3	V2 10007	Display Standards, Icon Library, and Labeling Plan	Each program shall establish display standards, an icon library, and a labeling plan.		
10.1.3.4	V2 10008	Units of Measure	Units of measure shall be consistent across like items.		
10.1.3.5	V2 10009	Crew Interface Operations Standardization	Methods of operating crew interfaces shall be standardized within and across system elements.		
10.1.3.6	V2 10010	Consistent Layout	Crew interfaces shall use consistent control and display layout within and across system elements.		
10.1.3.7	V2 10011	Displays and Controls Commonality	Display and control interfaces performing similar functions shall have commonality.		
10.1.3.8	V2 10012	Consistent Procedures	Procedures for performing similar tasks shall be consistent.		
10.1.4.1	V2 10013	Display and Control Distinctions	Display and control actions that result in different outcomes shall be distinguishable to preclude unintended results.		
10.1.4.2	V2 10014	Syntax Distinction	The syntax of any two commands that result in different outcomes shall be distinguishable to preclude issuing of the unintended command.		
10.1.5.1	V2 10015	Use of Cognitive Aids	The system shall provide cognitive aids to reduce the demand on crewmember memory to allow the crew to accomplish their tasks within the required performance parameters.		
10.1.5.2	V2 10016	Cue Saliency	Cue saliency shall be consistent with the importance of the message to be conveyed and urgency of response.		
10.1.6.1	V2 10017	System Health and Status	The system shall provide system health and status information to the crew, either automatically or by request.		
10.1.6.2	V2 10018	System Messages	System messages shall be specific and informative.		
10.1.6.3	V2 10022	Stale, Missing, or Unavailable Data	The system shall provide unique feedback when a data parameter is stale, missing, or unavailable.		
10.1.6.4	V2 10021	Control Feedback	The system shall provide a positive indication of crew-initiated control activation.		

Section	Rqmt #	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
10.1.6.5	V2 10020	Maximum System Response Times	The system shall provide feedback to the crew within the time specified in Table 22, Maximum System Response Time(s).		
10.1.6.6	V2 10200	LED Indicator Light Characteristics	The system shall implement LED indicator lights that meet the characteristics shown in Table 31, LED Indicator Light Characteristics.		
10.1.7.1	V2 10023	Current Procedure Step	The system shall indicate to the crew which step in the electronically displayed procedure is currently being executed.		
10.1.7.2	V2 10024	Completed Procedure Steps	The system shall indicate to the crew which steps in the electronically displayed procedure have been completed.		
10.1.7.3	V2 10025	View of Procedure Steps	The system shall provide a method for viewing prior and future steps in the electronically displayed procedure.		
10.1.7.4	V2 10026	Procedure Flexibility	The system shall provide a method for the crew to make real-time insertion, deletion, and rearrangement of electronic procedures.		
10.1.8.1	V2 10027	Inadvertent Operation Prevention	Control systems shall be designed to prevent inadvertent operation.		
10.1.8.2	V2 10028	Inadvertent Operation Recovery	Control systems shall allow for recovery from inadvertent operation and accidental changes in system status.		
10.2.1.1	V2 10030	Display and Control Location and Design	Displays and controls shall be designed and located so that they are operable to the required degree of accuracy in expected operating positions and conditions.		
10.2.1.2	V2 10031	High Priority Displays and Controls	Emergency, critical, important, and most frequently used displays and controls shall be located in the most prominent crew viewing and operating zones.		
10.2.2	V2 10032	Display and Control Grouping	Displays and controls shall be grouped according to purpose or function.		
10.2.3.1	V2 10033	Display-Control Relationships	All display-control relationships shall be logical and explicit.		
10.2.3.2	V2 10034	Display and Control Movement Compatibility	Displays shall be compatible with control movement, e.g., control motion to the right is compatible with clockwise roll, right turn, and direct movement to the right.		
10.2.3.3	V2 10035	Display and Control Sequence of Use	Displays and controls shall be arranged in relation to one another according to their sequence of use.		
10.3.1.1	V2 10036	Display Identifying Features	Displays shall have identifying features (such as location, size, shape, and color) that allow the crew to correctly navigate, locate, and identify the display in a timely manner.		
10.3.1.2	V2 10037	Display Area	The system shall provide the display area to present all critical task information within a crewmember's field of regard.		
10.3.2.1	V2 10038	Display Interpretation	Displays shall be accurately interpretable within the time required to meet mission needs.		
10.3.2.2	V2 10039	Display Readability	Displays shall be readable by the crewmember from the crewmember’s operating locations and orientation.		
10.3.2.3	V2 10040	Display Information	Information displayed shall contain only what is needed for the crew to maintain SA, diagnose, make decisions, plan responses, and perform the required tasks.		
10.3.2.4	V2 10042	Display Information Flow	Information displayed shall be grouped, arranged, and located to support task flow.		
10.3.2.5	V2 10043	Display Navigation	Display navigation shall allow the crewmember to move within and among displays without loss of SA and in a timely manner.		
10.3.2.6	V2 10044	Display Nomenclature	The nomenclature for each item or process shall be self-explanatory and direct the crew to the function or usage of the item.		

Section	Rqmt #	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
10.3.2.7	V2 10045	Display Coding Redundancy	For critical information and critical tasks when color is used to convey meaning, the system shall provide an additional cue.		
10.3.2.8	V2 10046	Measurement Units	Units of measure shall be displayed with their corresponding values.		
10.3.3.1	V2 10047	Visual Display Legibility	Displays shall be legible in the viewing conditions expected during task performance.		
10.3.3.2	V2 10048	Visual Display Parameters	Displays shall meet the visual display requirements in Table 23, Visual Display Parameters.		
10.3.3.3	V2 10049	Visual Display Character Parameters	Displays shall meet the visual display character requirements in Table 24, Visual Display Character Parameters.		
10.3.3.4	V2 10050	Display Font	Font size and type shall be selected to ensure acquisition, readability, and interpretability of visual displays.		
10.3.4.1.1	V2 10052	Intelligibility of Electronically Stored Speech Messages	Electronically stored speech messages from audio displays shall have 100% intelligibility and discriminability between the ensemble of different messages the audio display is programmed to produce (as measured under realistic background noise conditions and at locations where the display will be used).		
10.3.4.1.2	V2 10053	Sound Pressure Level	The system shall provide SPLs above background noise and compliant with acoustic limits to ensure audio display usability.		
10.3.4.1.3	V2 10054	Sound Distortion Level	The system shall provide audio signals with a minimal level of distortion and an appropriate frequency range to ensure usability of the audio display.		
10.3.4.1.4	V2 10055	Distinguishable and Consistent Alarms	The system shall provide distinguishable and consistent alarms to ensure audio display usability.		
10.3.4.2.1	V2 10056	Audio Display Sound Level	The system shall produce non-speech auditory annunciations with an SPL that meets at least one of the following criteria:a. Using measurements of A-weighted sound levels (ISO 7731:2003(E), Ergonomics – Danger signals for public and work areas – Auditory danger signals, method a in section 5.2.2.1), the difference between the two A-weighted SPLs of the signal and the ambient noise is greater than 15 dBA (LS,A to LN,A > 15 dBA). This method must be used for alarms intended to wake sleeping crewmembers, with the loudspeaker alarm volume adjusted to its minimum setting.b. Using measurements of octave band SPLs (ISO 7731:2003(E), method b in section 5.2.3.1), the SPL of the signal in one or more octave bands is greater than the effective masked threshold by at least 10 dB in the frequency range from 250 Hz to 4,000 Hz (LSi,oct to Lti,oct > 10 dB).c. Using measurements of 1/3-octave band SPLs (ISO 7731:2003(E), method c in section 5.2.3.2), the SPL of the signal in one or more 1/3-octave bands is greater than the effective masked threshold by 13 dB in the frequency range from 250 Hz to 4,000 Hz (LSi,1/3oct to LTi,1/3oct > 13 dB).		
10.3.4.2.2	V2 10057	Reverberation Time	The system shall provide a reverberation time of less than 0.6 seconds within the 500-Hz, 1-kHz, and 2-kHz octave bands.		
10.3.4.2.3	V2 10058	Frequency	Frequency content of auditory alarms shall correspond to maximal human sensitivity (200 Hz to 4 kHz).		
10.3.5.1	V2 10060	Label Provision	Labels shall be provided, as necessary, for the crew to identify items, interpret and follow nominal and contingency procedures, and avoid hazards.		
10.3.5.2	V2 10061	Label Standardization	Labels shall be consistent and standardized throughout the system.		
10.3.5.3	V2 10062	Label Display Requirements	Labels shall meet the requirements of visual displays (section 10.3.3, Visual Display Devices, in this NASA Technical Standard), except font height ([V2 10066] Label Font Height in this NASA Technical Standard).		
10.3.5.4	V2 10063	Label Location	Labels shall be positioned on or directly adjacent to the item they are labeling.		

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10.3.5.5	V2 10064	Label Categories	Labels shall be categorized by type, e.g., safety, procedure, and identification, with each label type having standardized, visually distinct characteristics.		
10.3.5.6	V2 10065	Label Distinction	Labels shall be easily recognizable and distinguishable from other labels.		
10.3.5.7	V2 10066	Label Font Height	Font height of 0.4 degrees or greater shall be used on labels.		
10.4.1	V2 10067	Control Shape	The shape of a control shall not interfere with ease of control manipulation.		
10.4.2.1	V2 10068	Control Identification	Controls that are intended for out-of-view operation shall be spatially or tactually distinct from one another.		
10.4.2.2	V2 10069	Emergency Control Coding	The system shall provide coding for emergency controls that are distinguishable from non-emergency controls.		
10.4.3.1	V2 10070	Control Size and Spacing	The size and spacing of controls shall be optimized for operation by the expected body part, e.g., finger, hand, foot, and expected clothing.		
10.4.3.2	V2 10071	Control Arrangement and Location	The arrangement and location of functionally similar or identical controls shall be consistent throughout the system.		
10.4.3.3	V2 10072	Control Proximity	Controls used by a restrained or unrestrained crewmember shall be located within the functional reach zones of the crew.		
10.4.3.4	V2 10073	Control Operation Supports and Restraints	The system shall provide body or limb supports and restraints that enable accurate crew control of applicable interfaces and prevent inadvertent control inputs during expected microgravity, acceleration, and vibration conditions.		
10.4.4.1	V2 10074	Control Operating Characteristics	Controls shall have operating characteristics, e.g., control type, forces, response rate, response latency, tactile feedback, to allow the crew to make the controlled item respond with the required levels of accuracy, precision, and speed.		
10.4.4.2	V2 10075	Control Input-Response Compatibility	Controls shall be compatible with the resulting system response.		
10.4.4.3	V2 10076	Control Latency	The system shall provide controls such that the crew is unimpeded by the time lag between the operation of a control and the associated change in system state.		
10.4.4.4	V2 10077	Control Resistive Force	Control resistive force shall prevent unintended drifting or changing of position.		
10.4.4.5	V2 10078	Detent Controls	Detent controls shall be provided when control movements occur in discrete steps.		
10.4.4.6	V2 10079	Stops Controls	Stops shall be provided at the beginning and end of a range of control positions, if the control is not required to be operated beyond the end positions or specified limits.		
10.4.5	V2 10080	Command Confirmation	Crew confirmation shall be required before completing critical, hazardous, or destructive commands.		
10.4.6.1	V2 10081	Suited Control Operations	Controls to be used by suited crewmembers shall be operable by a suited crewmember.		
10.4.6.2	V2 10082	Suited Control Spacing	Controls to be used by suited crewmembers shall be spaced such that they can be operated by a suited crewmember without inadvertent operation of adjacent controls.		
10.5.1	V2 10083	Communication System Design	Communication systems shall be designed to support coordinated and collaborative distributed teamwork.		
10.5.2	V2 10084	Communication Capability	The system shall provide the capability to send and receive communication among crewmembers, spacecraft systems, and ground systems to support crew performance, behavioral health, and safety.		
10.5.3.1	V2 10085	Communication Speech Levels	Audio communication systems shall allow crew to communicate with one another and with the ground at normal speech levels and with expected background SPLs.		
10.5.3.2	V2 10086	Communication Operational Parameters	The audio communication system shall provide intelligible speech by addressing system operational parameters, including frequency, dynamic range, noise cancelling and shields, pre-emphasis, and peak clipping.		

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10.5.3.3	V2 10087	Communication Environmental Parameters	The audio communication system shall provide intelligible speech by addressing appropriate background sound levels and architectural acoustical characteristics for both transmitter and receiver area.		
10.5.3.4	V2 10088	Communication Controls and Procedures	To ensure intelligibility, audio communications shall address operating controls and procedures, including volume, squelch, natural language, acknowledgement feedback, and muting.		
10.5.3.5	V2 10089	Communication Transmitter and Receiver Configuration	To ensure intelligibility, audio communications shall address transmitter and receiver configuration, e.g., headsets, microphones, air conduction, and bone conduction.		
10.5.3.6	V2 10090	Audio Communications Quality	The audio communication system shall provide speech quality that does not impact crew performance.		
10.5.3.7	V2 10091	Speech Intelligibility	For critical communications, the system shall ensure 90% English word recognition, using ANSI/ASA S3.2-2009, Method for Measuring the Intelligibility of Speech over Communication Systems.		
10.5.3.8	V2 10093	Private Audio Communication	The system shall provide the capability for private audio communication with the ground.		
10.5.4.1	V2 10094	Video Communications Visual Quality	Video communications shall employ digital encoding or alternate coding of equivalent visual quality.		
10.5.4.2	V2 10095	Video Communications Spatial Resolution	Video communications shall provide sufficient spatial resolution (width and height in pixels) to accomplish relevant tasks.		
10.5.4.3	V2 10096	Video Communications Temporal Resolution	Video communications shall provide sufficient temporal resolution (frames/s) to accomplish relevant tasks.		
10.5.4.4	V2 10097	Video Communications Color and Intensity	Video communications shall provide sufficient color and intensity levels to accomplish relevant tasks.		
10.5.4.5	V2 10098	Video Communications Bit Rate	Video communications systems shall support bit rates high enough to ensure that compression artifacts are as low as reasonably achievable.		
10.5.4.6	V2 10099	Audio-Visual Lag Time	Communications systems that carry sound and video that are intended to be synchronized shall ensure that the sound program does not lead the video program by more than 15 ms or lag the video program by more than 45 ms.		
10.6.1	V2 10100	Automated and Robotic System Provision	Automated or robotic systems shall be provided when crew cannot reliably, safely, or efficiently perform assigned tasks.		
10.6.2	V2 10101	Automated and Robotic System Safety	Automated and robotic systems shall include safeguards to prevent mission degradation, equipment damage, or injury to crew.		
10.6.3	V2 10102	Robotic Control Stations – Common and Consistent	For a given robotic system, operator control stations shall be common and consistent, independent of physical location, e.g., on Earth, in space, on the lunar surface, or on a planetary surface.		
10.6.4	V2 10104	Automation Levels	Crew interfaces to automated and robotic systems shall support the appropriate level(s) of automation to accomplish the task effectively.		
10.6.5	V2 10105	Automation Level Status Indication	Crew interfaces to automation shall provide information on the status of the automation, including when the system changes between levels of automation.		
10.6.6	V2 10106	Robotic System Status	Crew interfaces to robotic assets shall provide information on the status of the robotic asset, including health, past and intended future actions, procedural information, and the ability of the robotic asset to comprehend and accept operator commands.		

Section	Rqmt #	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
10.6.7	V2 10108	Automated and Robotic System Operation – with Communication Limitations	Automated and robotic systems shall be capable of receiving and sending commands and performing tasks in the presence of a communication latency and intermittent transmission related to remote operations.		
10.6.8	V2 10109	Automated and Robotic System Shutdown Capabilities	Crew interfaces shall provide the ability to shut down automated and robotic systems.		
10.6.9	V2 10110	Automation and Robotics Override Capabilities	Crew interfaces shall provide the ability to override automated and robotic systems.		
10.6.10	V2 10112	Crew Interfaces to Robotic Systems - Frames of Reference	Crew interfaces to robotic systems shall be designed to enable effective and efficient coordination of or shifting between multiple frames of reference.		
10.7.1	V2 10113	Information Management Capabilities – Provision	The information management system shall provide data critical to mission planning, mission operations, system maintenance, and system health and status at an appropriate level of detail to support effective and efficient crew performance.		
10.7.2.1	V2 10114	Visual and Audio Annunciations	The information management system shall provide visual and audio annunciations to the crew for emergency, warning, and caution events.		
10.7.2.2	V2 10115	Automatic Set-Point Alerts	The system shall alert the crew if the selected set-points are outside safe limits.		
10.7.2.3	V2 10116	Audio Annunciation Silencing	The information management system shall provide a manual silencing feature for active audio annunciations.		
10.7.2.4	V2 10117	Visual and Auditory Annunciation Failures	The information management system shall test for a failure of the visual and auditory annunciators upon crew request.		
10.7.2.5	V2 10118	Visual Alerts - Red	The color red shall be used as a visual indicator for the highest alert level.		
10.7.2.6	V2 10119	Visual Alerts - Yellow	The color yellow shall be used as a visual indicator for the second highest alert level.		
10.7.3.1	V2 10120	Information Management Methods and Tools	The information management system shall provide methods and tools that allow the crew to effectively input, store, receive, display, process, distribute, update, and dispose of mission data.		
10.7.3.2	V2 10121	Information Management Standard Nomenclature	The information management system shall use standard nomenclature.		
10.7.3.3	V2 10122	Information Management Compatibility	The information management system shall be compatible with other systems within the spacecraft.		
10.7.3.4	V2 10123	Information Management Operation Rate	The information management system shall operate at a rate that enables the crew to perform tasks effectively and efficiently, e.g., within acceptable error limits and scheduled operating times.		
10.7.3.5	V2 10124	Information Management Data Provision	The information management system shall provide the crew with data to perform tasks at each workstation where those tasks are to be performed.		
10.7.3.6	V2 10125	Information Management Security	The information management system shall have features for the protection of sensitive and private data, transmission, secure viewing, and sender verification.		
10.7.3.7	V2 10126	Information Management Ground Access	The information management system shall allow for ground access to perform all onboard database functions without crew intervention.		
10.7.3.8	V2 10127	Information Capture and Transfer	The information management system shall provide a capability for the crew to capture and transfer information in a portable fashion.		
10.7.3.9	V2 10128	Information Annotation	The information management system shall provide a capability for annotation by the crew.		
10.7.3.10	V2 10129	Information Backup and Restoration	The information management system shall provide for crew-initiated data backup and restoration for all mission data and automatic backup for critical data.		

Section	Rqmt #	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
10.7.3.11	V2 10130	Alternative Information Sources	The information management system shall provide alternative information sources for use in the event of the loss of the information management system.		
10.7.3.12	V2 10131	Software System Recovery	The information management system shall be rapidly recoverable from a software system crash.		
11.1.1	V2 11001	Suited Donning and Doffing	The system shall accommodate efficient and effective donning and doffing of spacesuits for both nominal and contingency operations.		
11.1.2.1	V2 11006	Suit Pressure Set-Points	The suit shall provide the capability for the crewmember to select discrete suit pressure set-points within the suit operating pressure ranges during pressurized and unpressurized suited operations.		
11.1.2.2	V2 11007	Suit Equilibrium Pressure	Suits shall maintain pressure within 1.72 kPa (0.25 psi) after the suit has achieved an equilibrium pressure for a set-point.		
11.1.2.3	V2 11009	Continuous Noise in Spacesuits	Suits shall limit suit-induced continuous noise exposure at the ear to NC-50 or below without the use of auxiliary hearing protection.		
11.1.2.4	V2 11010	EVA Suit Radiation Monitoring	The suit shall provide or accommodate radiation monitoring and alerting functions to allow the crew to take appropriate actions.		
11.1.2.5	V2 11011	Suited Crewmember Heat Storage	The system shall prevent the energy stored by each crewmember during nominal suited operations from exceeding the limits defined by the range 3.0 kJ/kg (1.3 Btu/lb) > ΔQ stored > 1.9 kJ/kg (-0.8 Btu/lb), where ΔQ stored is calculated using the 41 Node Man or Wissler model.		
11.1.3.1	V2 11013	Suited Body Waste Management – Provision	Suits shall provide for management of urine, feces, menses, and vomitus of suited crewmembers.		
11.1.3.2	V2 11028	EVA Suit Urine Collection	EVA suits shall be capable of collecting a total urine volume of Vu = 0.5 +2.24t/24 L, where t is suited duration in hours.		
11.1.3.3	V2 11014	LEA Suit Urine Collection	LEA suits shall be capable of collecting a total urine volume of Vu = 0.5 + 2t/24 L throughout suited operations, where t is suited duration in hours.		
11.1.3.4	V2 11015	Suit Urine Collection per Day - Contingency	For contingency suited operations lasting longer than 24 hours, suits shall be capable of collecting and containing 1 L (33.8 fl oz) of urine per crewmember per day.		
11.1.3.5	V2 11016	Suit Feces Collection per Day – Contingency	During contingency suited operations, suits shall be capable of collecting 75 g (0.17 lb) (by mass) and 75 mL (2.5 fl oz) (by volume) of fecal matter per crewmember per day.		
11.1.3.6	V2 11017	Suit Isolation of Vomitus	Suits shall be shown to not create any catastrophic hazards in the event of vomitus from the crewmember.		
11.1.4.1	V2 11018	Suited Field of Regard	Suits shall provide a field of regard sufficient to allow the crewmember to accomplish required suited tasks.		
11.1.4.2	V2 11019	Suit Helmet Optical Quality	Suit helmets shall have sufficient optical qualities to allow the crewmember to accomplish required suited tasks and maintain a level of SA necessary to maintain safety.		
11.1.4.3	V2 11020	Suit Helmet Luminance Shielding	Suit helmets shall provide protection to suited crewmembers from viewing objects with luminance that could prevent successful completion of required suited tasks.		
11.1.4.4	V2 11021	Suit Helmet Visual Distortions	Suit helmets shall be free from visual distortion.		
11.1.4.5	V2 11022	Suit Helmet Displays	Suit helmet field of regard shall be unencumbered if helmet- or head-mounted displays are provided.		
11.1.5	V2 11023	Suit Information Management	The system shall allow the crewmember to effectively input, store, receive, display, process, distribute, update, monitor and dispose of relevant information on consumable levels, suit status and alerts, and biomedical data.		

Section	Rqmt #	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
11.1.6	V2 11100	Pressure Suits for Protection from Cabin Depressurization	The system shall provide the capability for crewmembers to wear pressure suits for sufficient duration during launch, entry, descent (to/from Earth, or other celestial body) and any operation deemed high risk for loss of crew life due to loss of cabin pressurization (such as in mission dockings, operations during periods of high incidence of Micrometeoroids and Orbital Debris (MMOD) or complex vehicle maneuvers).		
11.2.1	V2 11024	Ability to Work in Suits	Suits shall provide mobility, dexterity, and tactility to enable the crewmember to accomplish suited tasks within acceptable physical workload and fatigue limits while minimizing the risk of injury.		
11.2.2	V2 11025	Suited Nutrition	The system shall provide a means for crewmember nutrition in pressure suits designed for surface (e.g., Moon or Mars) EVAs of more than 4 hours in duration or any suited activities greater than 12 hours in duration.		
11.2.3.1	V2 11029	LEA Suited Hydration	The system shall provide a means for on-demand crewmember hydration while suited, including a minimum quantity of potable water of 2 L (67.6 fl oz) per 24 hours for the LEA suit.		
11.2.3.2	V2 11030	EVA Suited Hydration	The system shall provide a means for on-demand crewmember hydration while suited, including a minimum quantity of potable water of 240 mL (8.1 fl oz) per hour for EVA suited operations.		
11.2.4	V2 11027	Suited Medication Administration	The system shall provide a means for administration of medication to a suited, pressurized crewmember for pressurized suited exposures greater than 12 hours.		
11.2.5	V2 11031	Suited Relative Humidity	For suited operations, the system shall limit RH to the levels in Table 25, Average Relative Humidity Exposure Limits for Suited Operations.		
11.2.6	V2 11032	LEA Suited Decompression Sickness Prevention Capability	LEA spacesuits shall be capable of operating at sufficient pressure to protect against Type II decompression sickness in the event of a cabin depressurization.		
11.3.1	V2 11033	Suited Thermal Control	The suit shall allow the suited crewmembers and remote operators to adjust the suit thermal control system.		
11.3.2	V2 11034	Suited Atmospheric Data Recording	Systems shall automatically record suit pressure, ppO2, and ppCO2.		
11.3.3	V2 11035	Suited Atmospheric Data Displaying	Suits shall display suit pressure, ppO2, and ppCO2 data to the suited crewmember.		
11.3.4	V2 11036	Suited Atmospheric Monitoring and Alerting	Suits shall monitor suit pressure, ppO2, and ppCO2 and alert the crewmember when they are outside safe limits.		
11.3.5	V2 11039	Nominal Spacesuit Carbon Dioxide Levels	The spacesuit shall limit the inspired CO2 partial pressure (PICO2) in accordance with Table 26, Spacesuit Inspired Partial Pressure of CO2 (PICO2) Limits.		
11.4.1	V2 11037	EVA Suited Metabolic Rate Measurement	The system shall measure or calculate metabolic rates of suited EVA crewmembers.		
11.4.2	V2 11038	EVA Suited Metabolic Rate Display	The system shall display metabolic data of suited EVA crewmembers to the crew.		
11.5	V2 11101	Incapacitated Crew Rescue (ICR)	Resources shall be provided to rescue an incapacitated suited crewmember(s).		
12.1.1	V2 12003	System Assumptions	Each human space flight program shall document the system support design and environment: a. Work environment (e.g., lighting, heating, atmosphere, gravity). b. Tools and support equipment. c. Ground support personnel characteristics (e.g., size, training, experience, number, physical and cognitive capabilities, skills).		

Section	Rqmt #	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
12.1.2.1	V2 12004	Anthropometry, Biomechanics, Range of Motion, and Strength	Each program shall identify an anthropometry, biomechanics, range of motion, and strength data set for the ground support population to be accommodated in support of all requirements in this section of this NASA Technical Standard.		
12.1.2.2	V2 12005	Protective Equipment	The system shall accommodate ground personnel protective equipment and attire.		
12.1.2.3	V2 12006	Volume Accommodation	The system shall provide the volume necessary for the ground support personnel to perform all ground processing tasks using the required tools and equipment.		
12.1.2.4	V2 12007	Ground Processing – Induced Forces	Systems, hardware, and equipment shall be protected from or be capable of withstanding forces imposed by the ground support personnel or ground support equipment (GSE), in a 1-g environment.		
12.1.2.5	V2 12008	Systems Accessibility	System components, hardware, and/or equipment that requires ground support personnel inspection or interaction shall be accessible.		
12.1.2.6	V2 12009	Tool Clearance	The system shall provide tool clearances for tool installation and actuation for all tool interfaces during ground processing.		
12.1.3.1	V2 12010	Flight Hardware Differentiation	Flight system components that have the same or similar form but different functions shall not be physically interchangeable.		
12.1.3.2	V2 12011	Hardware Protection	The system shall provide a means of protecting flight hardware and equipment from damage during ground processing.		
12.1.3.3	V2 12012	Mobility Aids	The system shall provide mobility aids to support expected ground support personnel tasks.		
12.1.3.4	V2 12013	Equipment Handling Design	All items designed to be carried, supported, or removed and replaced shall have a means for grasping, handling, and carrying.		
12.1.3.5	V2 12014	Inadvertent Operation Prevention	The system shall be designed to prevent inadvertent operation of controls during ground processing.		
12.1.3.6	V2 12015	Incorrect Installation Prevention	System hardware and equipment shall be designed to prevent incorrect mounting or installation.		
12.1.3.7	V2 12016	Pre-Defined Tool Set	The system shall be designed to be assembled, prepared for launch, maintained, and reconfigured using a pre-defined set of standard tools and lesser set of any pre-established set of specialized tools.		
12.1.3.8	V2 12017	Captive Fasteners	Fasteners on installable units shall be captive.		
12.1.3.9	V2 12018	Ground Processing Without Damage	The system shall be designed for assembly, testing and checkout, troubleshooting, and maintenance that prevents damage to other components.		
12.1.3.10	V2 12019	Replaceable Items	The system shall locate maintenance items so that a planned ground processing or corrective or preventive maintenance task does not require the deintegration or demating of other systems or components.		
12.1.3.11	V2 12020	Visual Access for Ground Processing	The system shall provide direct line-of-sight visual access to all flight system components requiring inspections or other human-system interactions, except self-mating connectors, on which ground processing is performed by ground personnel.		
12.1.3.12	V2 12021	Lighting	The flight system in combination with ground support equipment shall provide lighting to perform ground processing tasks in the vehicle.		
12.1.3.13	V2 12022	Supplemental Systems	The system shall be designed to support any supplemental systems that are required to assist ground support personnel when an assigned task cannot reliably, safely, or effectively be performed by ground support personnel alone.		
12.1.3.14	V2 12023	Operational Consistency	The system shall be designed for consistent operation across ground processing tasks.		
12.1.3.15	V2 12024	Restraints and Platforms	The system shall accommodate restraint and platform placement that ensures the reach and work envelope of the suited or unsuited ground support personnel for the required tasks.		

Section	Rqmt #	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
12.1.3.16	V2 12025	System Feedback	The system shall provide feedback to the operator indicating successful task completion.		
12.1.3.17	V2 12026	Stowage Access	The system shall provide access for ground support personnel to spacecraft stowage volumes that require late loading and early unloading of items.		
12.1.3.18	V2 12027	Flight Software Systems	The system shall allow the ground support personnel safe operation of flight software systems for ground processing.		
12.1.4.1	V2 12028	Sharp Edge and Burr Injury Prevention	The system shall protect ground support personnel from injury resulting from sharp edges and burrs.		
12.1.4.2	V2 12029	Pinch Point Prevention	The system shall be designed to protect ground personnel from injury due to pinch points.		
12.1.4.3	V2 12030	Hazard Controls	The system shall be designed to prevent unnecessary exposure of ground support personnel and equipment to hazards, including spills, electrical shocks, and the release of stored energy.		
12.1.4.4	V2 12031	System Safing for Ground Operations	The system shall alert and allow ground personnel to safe the system before performing any ground operation.		
12.1.4.5	V2 12032	Contamination Controls	The system shall have controls in place to prevent the introduction of contaminants to the flight vehicle.		
12.1.4.6	V2 12033	Containment of Fluids and Gases	The system shall provide for containment and disposal of the inadvertent release of fluids and gases into the flight system.		
12.1.4.7	V2 12034	Safe Weight Limit	Hardware and equipment installed or removed by ground support personnel without ground support equipment shall be less than a safe weight limit.		
12.1.4.8	V2 12035	Safe Flight System Component Arrangement	Flight system components shall be designed, arranged, or located to prevent hazards, interference, or errors during concurrent ground processing tasks.		
12.1.5.1	V2 12036	Connector Design and Spacing	Connectors shall be designed and spaced to allow for accurate, damage-free mating and demating by ground support personnel.		
12.1.5.2	V2 12037	Connector Incorrect Mating Prevention	Connectors shall have physical features to preclude incorrect mating and mismating. This can be accomplished by differing connector shell sizes, differing connector keyway arrangements, and having different contact arrangements (these are listed in order of most preferred to least preferred).		
12.1.6.1	V2 12038	Label Provisions	Labels and placards shall be provided for the ground support personnel to identify items, interpret and follow procedures, and avoid hazards.		
12.1.6.2	V2 12039	Label Standardization	Labels and placards shall be consistent and standardized throughout the system.		
12.1.6.3	V2 12040	Label Content	The content of labels and placards shall be of sufficient size, color contrast, and character height and style to support readability.		
12.1.6.4	V2 12041	Readable Label Positioning	Labels and placards shall be located such that they are readable by the operator, considering ambient lighting conditions, orientation in the integrated configuration, and position of the operator relative to the label.		
12.1.6.5	V2 12042	Non-Obstructive Labels	Labels, placards, or part markings used for ground processing shall not visually or operationally interfere with space flight crew interface labeling.		
12.2.1	V2 12043	Emergency Egress at the Launch Site	The system shall be designed such that the space flight crew and ground support personnel can egress within the time required to preserve the health and safety of all space flight crew and ground support personnel in the event of an emergency.		
12.2.2	V2 12044	Emergency Egress to Medical Care	The system shall be designed to ensure space flight crew and ground support personnel can egress to a location providing advanced pre-hospital life support.		
12.2.3	V2 12045	Nominal Timely Egress	Following a post mission nominal landing, launch scrub, or abort scenario, crew egress from the system shall be expedited to ensure crew health.		

Section	Rqmt #	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
12.2.4	V2 12046	Emergency Egress Acceleration Limits	For ground emergency egress systems (EES), the system shall limit the magnitude and direction of crew exposure to accelerations according to Table 36, EES Acceleration Limits – Sustained, and Table 37, EES Acceleration Limits – Jerk.		

APPENDIX E

SPACESUIT SYSTEM APPLICABILITY MATRIX

E.1 PURPOSE

The purpose of this generic applicability matrix is to serve as a starting point for the tailoring process for future spacesuit designers by indicating those standards that are likely to impact design. While spacesuit-specific standards are described in section 11, several requirements from other sections of this NASA Technical Standard are also applicable to spacesuit systems. Spacesuit designers should work closely with HMTA to tailor the entirety of this NASA Technical Standard to the specific project based on unique mission attributes. Applicable standards for spacesuits are identified as applicable (APP) or not applicable(N/A). There are instances in which standards may or may not apply to spacesuit systems, because design approaches and operational concepts may differ significantly among different systems. For example, provision of treatment for decompression sickness may be provided by spacesuits or could alternatively be provided by other vehicle systems. In these instances, standards are designated as potentially applicable (PA). The applicability of standards to spacesuits is also dependent upon the spacesuits' intended functionality. Accordingly, all spacesuit-applicable standards are identified as being applicable to EVA spacesuits, LEA spacesuits, or both EVA and LEA spacesuits as defined below:

- LEA Spacesuit System Definition: Any spacesuit system designed for use during launch, entry, and abort phases of space flight, primarily to protect against toxic exposure, ebullism, hypoxia, and decompression sickness in the event of an unplanned cabin depressurization or toxic release into the cabin. It may also be worn during other dynamic phases of flight such as rendezvous and docking during which there is an increased risk of cabin depressurization due to cabin leaks. The duration for which LEA spacesuits are designed to operate will depend on mission scenarios and may range from a few hours to several days per use.

- EVA Spacesuit System Definition: Any spacesuit system designed to allow astronauts to perform tasks outside of a spacecraft or habitat. Performance of space flight EVA consists of placing a human in a micro-environment that has to provide all the life support, nutrition, hydration, waste, and consumables management function of an actual space vehicle, while allowing crewmembers to perform mission tasks. EVA spacesuits are designed to be used for durations of less than a day due to potential human and suit system constraints. This includes all suited phases (e.g., prebreathe, leak checks, airlock depress).

The Interface column is an important component of the Applicability Matrix, whose purpose is to identify standards that are applicable to interfaces between spacesuits and other systems rather than directly to spacesuits themselves. Standards that require consideration of the suit/system interface are identified in the Interfaces column by an "X" and should be reviewed by designers of both spacesuits and other systems to ensure compatibility among all systems in the context of the overall system and mission design. For example, if the suit is being designed for an existing vehicle, the suit has to be designed to fit through existing hatches. However, if the vehicle has not yet been built, the suit design may influence the size of the hatches. As another example, the fire protection system standards are marked as an interface interaction to capture the scenario in which any suited crew should be alerted to potential issues regarding the vehicle and its fire protection system. Standards that have interface applicability should be considered especially in situations where one of the systems is pre-existing. While effort was made to identify those standards that are likely to directly impact spacesuit design, standards that are marked as N/A should still be examined. This is especially important in those instances in which the Interfaces column has been marked, as these standards have the potential to influence both spacesuit and vehicle design.

Table 39—Suit System Applicability Matrix

Section	Rqmt #	Description	EVA	LEA/IVA	Interfaces
3.1.1		Full Mission Duration Applicability			
3.2.1	V2 3006	Human-Centered Task Analysis			
3.2.2	V2 3102	Human Error Analysis			
3.2.3	V2 3101	Iterative Developmental Testing			
4.1.1	V2 4102	Functional Anthropometric Accommodation	APP	APP	
4.1.2	V2 4103	Body Mass, Volume, and Surface Area Data	APP	APP	
4.1.3.1	V2 4104	Crew Operational Loads	APP	APP	
4.1.3.2	V2 4105	Withstand Crew Loads	APP	APP	
4.2	V2 4013	Muscle Effects	APP	APP	
4.3	V2 4015	Aerobic Capacity	APP	APP	
5.1.1	V2 5001	Visual Capabilities	APP	APP	
5.1.2	V2 5002	Auditory Perceptual Capabilities	APP	APP	
5.1.3	V2 5003	Sensorimotor Capabilities	APP	APP	
5.1.4	V2 5004	Cognitive Capabilities	APP	APP	
6.1	V2 6001	Trend Analysis of Environmental Data	APP	APP	
6.2.1.1	V2 6002	Inert Diluent Gas	N/A	N/A	
6.2.1.2	V2 6003	O2 Partial Pressure Range for Crew Exposure	APP	APP	
6.2.1.3	V2 6004	Nominal Vehicle/Habitat Carbon Dioxide Levels	N/A	N/A	
6.2.2.1	V2 6006	Total Pressure Tolerance Range for Indefinite Crew Exposure	APP	APP	
6.2.2.2	V2 6007	Rate of Pressure Change	APP	APP	
6.2.2.3	V2 6150	Barotrauma Prevention			
6.2.2.4	V2 6008	Decompression Sickness (DCS) Risk Identification	APP	APP	
6.2.2.5	V2 6009	Decompression Sickness Treatment Capability	PA	PA	X
6.2.3	V2 6011	Post Landing Relative Humidity (RH)	N/A	N/A	
6.2.4.1	V2 6012	Crew Health Environmental Limits	N/A	PA	X
6.2.4.2	V2 6013	Crew Performance Environmental Zone			
6.2.4.3	V2 6151	Temperature Selectability			
6.2.4.4	V2 6152	Temperature Adjustability			
6.2.4.5	V2 7041	Environmental Control	N/A	N/A	
6.2.5	V2 6017	Atmospheric Control	N/A	N/A	X
6.2.6.1	V2 6020	Atmospheric Data Recording	N/A	N/A	
6.2.6.2	V2 6021	Atmospheric Data Displaying	N/A	N/A	
6.2.7.1	V2 6022	Atmospheric Monitoring and Alerting Parameters	N/A	N/A	
6.2.7.2	V2 6023	Trace Constituent Monitoring and Alerting	N/A	N/A	

Section	Rqmt #	Description	EVA	LEA/IVA	Interfaces
6.2.7.3	V2 6024	Combustion Monitoring and Alerting	N/A	N/A	X
6.2.7.4	V2 6025	Contamination Monitoring and Alerting	N/A	N/A	X
6.2.7.5	V2 6153	Celestial Dust Monitoring and Alerting			
6.2.8.1	V2 6107	Nominal Vehicle/Habitat Atmospheric Ventilation			
6.2.8.2	V2 6108	Off-Nominal Vehicle/Habitat Atmospheric Ventilation			
6.2.9.1	V2 6050	Atmosphere Contamination Limit	APP	APP	
6.2.9.2	V2 6052	Particulate Matter	N/A	N/A	X
6.2.9.3	V2 6053	Lunar Dust Contamination	PA	N/A	X
6.2.9.4	V2 6059	Microbial Air Contamination	APP	APP	
6.3.1.1	V2 6026	Potable Water Quality	APP	APP	X
6.3.1.3	V2 6051	Water Contamination Control	APP	APP	
6.3.1.4	V2 6046	Water Quality Monitoring	N/A	N/A	X
6.3.2	V2 6109	Water Quantity			
6.3.3	V2 6110	Water Temperature			
6.3.4.1	V2 6039	Potable Water Dispensing Rate	N/A	N/A	
6.3.4.2	V2 6040	Potable Water Dispensing Increments	N/A	N/A	
6.4.1.1	V2 6047	Toxic Hazard Level Three	APP	APP	
6.4.1.2	V2 6048	Toxic Hazard Level Four	APP	APP	
6.4.1.3	V2 6049	Chemical Decomposition	APP	APP	
6.4.2.1	V2 6060	Biological Payloads	N/A	N/A	
6.4.2.2	V2 6061	Environment Cross-Contamination	APP	APP	
6.4.3	V2 6062	Availability of Environmental Hazards Information	N/A	N/A	X
6.4.4	V2 6063	Contamination Cleanup	APP	APP	X
6.5.1	V2 6064	Sustained Translational Acceleration Limits	N/A	N/A	X
6.5.2.1	V2 6065	Rotational Velocity	N/A	N/A	X
6.5.2.2	V2 6066	Sustained Rotational Acceleration Due to Cross-Coupled Rotation	N/A	N/A	X
6.5.2.3	V2 6067	Transient Rotational Acceleration	N/A	N/A	X
6.5.3	V2 6069	Acceleration Injury Prevention	N/A	APP	X
6.5.4	V2 6070	Injury Risk Criterion	N/A	APP	X
6.5.5	V2 6111	Dynamic Mission Phases Monitoring and Analysis			
6.5.6	V2 6112	Hang Time Limit			
6.5.7	V2 6113	Crew Limits in Launch Orientation			
6.6.1.1	V2 6073	Launch, Entry, and Abort Noise Exposure Limits	N/A	APP	
6.6.1.2	V2 6074	Ceiling Limit for Launch and Entry	N/A	APP	
6.6.1.3	V2 6075	Ceiling Limit for Launch Abort	N/A	APP	
6.6.1.4	V2 6076	Launch, Entry, and Abort Impulse Noise Limits	N/A	APP	
6.6.1.5	V2 6077	Hazardous Noise Limits for All Phases Except Launch, Entry, and Abort	APP	N/A	
6.6.1.6	V2 6115	24-Hour Noise Exposure Limits			
6.6.1.7	V2 6078	Continuous Noise Limits	N/A	N/A	
6.6.1.8	V2 6079	Crew Sleep Continuous Noise Limits	N/A	N/A	
6.6.1.9	V2 6080	Intermittent Noise Limits	APP	APP	X
6.6.1.10	V2 6081	Alarm Maximum Sound Level Limit	APP	N/A	
6.6.1.11	V2 6082	Annoyance Noise Limits for Crew Sleep	N/A	APP	
6.6.1.12	V2 6083	Impulse Noise Limit	APP	APP	
6.6.1.13	V2 6084	Narrow-Band Noise Limits	APP	APP	X
6.6.1.14	V2 6085	Infrasonic Sound Pressure Limits	N/A	N/A	X
6.6.1.15	V2 6106	Noise Limit for Personal Audio Devices	APP	APP	
6.6.2.1	V2 6087	Acoustic Monitoring	N/A	N/A	X
6.6.2.2	V2 6088	Individual Noise Exposure Monitoring	N/A	N/A	

Section	Rqmt #	Description	EVA	LEA/IVA	Interfaces
6.7.1.1	V2 6089	Vibration during Pre-Flight	N/A	N/A	
6.7.1.2	V2 6090	Vibration Exposures during Dynamic Phases of Flight	N/A	N/A	X
6.7.1.3	V2 6091	Long-Duration Vibration Exposure Limits for Health during Non-Sleep Phases of Mission	APP	N/A	
6.7.1.4	V2 6092	Vibration Exposure Limits during Sleep	N/A	N/A	
6.7.1.5	V2 6093	Vibration Limits for Performance	PA	N/A	X
6.7.2	V2 6094	Hand Vibration	PA	N/A	X
6.8.1.1	V2 6095	Ionizing Radiation Protection Limit	N/A	N/A	
6.8.1.2	V2 6097	Crew Radiation Exposure Limits	APP	APP	
6.8.1.3	V2 6098	Radiation Environments	APP	APP	
6.8.1.4	V2 6099	Space Weather Monitoring	N/A	N/A	
6.8.1.5	V2 6100	Ionizing Radiation Alerting	PA	PA	
6.8.1.6	V2 6101	Ionizing Radiation Dose Monitoring	N/A	PA	
6.8.2.1	V2 6102	RF Non-Ionizing Radiation Exposure Limits	APP	APP	
6.8.2.2	V2 6103	Laser Exposure Limits	PA	PA	
6.8.2.3	V2 6104	Natural Sunlight Exposure Limits	APP	APP	
6.8.2.5	V2 6117	Artificial Light Exposure Limits for Ultraviolet (UV) Sources			
7.1.1.1	V2 7001	Food Quality	N/A	N/A	
7.1.1.2	V2 7002	Food Acceptability	N/A	N/A	X
7.1.1.3	V2 7003	Food Caloric Content	N/A	N/A	
7.1.1.4	V2 7004	EVA Food Caloric Content	N/A	N/A	X
7.1.1.5	V2 7100	Food Nutrient Composition	N/A	N/A	
7.1.1.6	V2 7007	Food and Production Area Microorganism Levels	N/A	N/A	
7.1.2.1	V2 7008	Food Preparation	N/A	N/A	X
7.1.2.2	V2 7009	Food Preparation and Cleanup	N/A	N/A	
7.1.2.3	V2 7010	Food Contamination Control	N/A	N/A	
7.1.2.4	V2 7011	Food and Beverage Heating	N/A	N/A	
7.1.2.5	V2 7012	Dining Accommodations	N/A	N/A	
7.1.2.6	V2 7014	Food Spill Control	APP	APP	
7.1.2.7	V2 7015	Food System Cleaning and Sanitizing	N/A	N/A	X
7.2.1	V2 7016	Personal Hygiene Capability	N/A	N/A	
7.2.2	V2 7017	Body Cleansing Privacy	N/A	N/A	
7.2.3	V2 7019	Hygiene Maintainability	N/A	N/A	
7.3.1.1	V2 7020	Body Waste Management Capability	N/A	N/A	
7.3.1.2	V2 7021	Body Waste Management System Location	N/A	N/A	
7.3.1.3	V2 7022	Body Waste Management Privacy	N/A	N/A	
7.3.1.4	V2 7023	Body Waste Management Provision	N/A	N/A	
7.3.1.5	V2 7024	Body Waste Accommodation	APP	APP	
7.3.1.6	V2 7025	Body Waste Containment	N/A	N/A	
7.3.1.7	V2 7026	Body Waste Odor	APP	APP	
7.3.1.8	V2 7027	Body Waste Trash Receptacle Accessibility	N/A	N/A	
7.3.1.9	V2 7029	Body Waste Management Maintenance	N/A	N/A	X
7.3.1.10	V2 7101	Body Waste Isolation			
7.3.2.1	V2 7102	Body Waste Quantities			
7.3.2.2	V2 7085	Fecal and Urine Elimination Concurrence			
7.3.2.3	V2 7035	Urine per Crewmember			
7.4.1	V2 7038	Physiological Countermeasures Capability	N/A	N/A	
7.4.2	V2 7040	Physiological Countermeasure Operations	N/A	N/A	
7.4.3	V2 7042	Orthostatic Intolerance Countermeasures	PA	PA	

Section	Rqmt #	Description	EVA	LEA/IVA	Interfaces
7.5.1	V2 7043	Medical Capability	N/A	N/A	
7.5.2	V2 7045	Medical Equipment Usability	N/A	N/A	X
7.5.3	V2 7046	Medical Treatment Restraints	N/A	N/A	
7.5.4	V2 7049	Deceased Crew	PA	PA	
7.6.1.1	V2 7050	Stowage Provisions	PA	PA	
7.6.1.2	V2 7051	Personal Stowage	N/A	N/A	
7.6.1.3	V2 7052	Stowage Location	N/A	N/A	X
7.6.1.4	V2 7053	Stowage Interference	N/A	N/A	
7.6.1.5	V2 7054	Stowage Restraints	PA	PA	
7.6.2.1	V2 7055	Priority of Stowage Accessibility	N/A	N/A	X
7.6.2.2	V2 7056	Stowage Operation without Tools	N/A	N/A	X
7.6.2.3	V2 7057	Stowage Access while Suited	APP	APP	X
7.6.3	V2 7058	Identification System	N/A	N/A	X
7.7.1	V2 7059	Inventory Tracking	N/A	N/A	X
7.7.2	V2 7060	Inventory Operations	N/A	N/A	X
7.7.3	V2 7061	Nomenclature Consistency	APP	APP	
7.7.4	V2 7062	Unique Item Identification	APP	APP	
7.7.5	V2 7063	Interchangeable Item Nomenclature	APP	APP	
7.8.1.1	V2 7064	Trash Accommodation	N/A	N/A	
7.8.1.2	V2 7065	Trash Volume Allocation	N/A	N/A	X
7.8.1.3	V2 7066	Trash Stowage Interference	N/A	N/A	
7.8.2	V2 7069	Labeling of Hazardous Waste	N/A	N/A	
7.9.1	V2 7070	Sleep Accommodation	N/A	N/A	
7.9.2	V2 7071	Behavioral Health and Privacy	N/A	N/A	
7.9.3	V2 7073	Partial-g Sleeping	N/A	N/A	
7.10.1	V2 7074	Clothing Quantity	N/A	N/A	
7.10.2	V2 7075	Clothing Exclusive Use	N/A	N/A	
7.10.3	V2 7076	Clothing Safety and Comfort	APP	APP	
7.11.1	V2 7079	Accessibility for Cleaning	APP	APP	
7.11.2	V2 7080	Particulate Control	APP	APP	
7.11.3	V2 7081	Microbial Surface Contamination	APP	APP	
7.11.4	V2 7082	Surface Material Cleaning	APP	APP	
7.11.5	V2 7083	Cleaning Materials	APP	APP	
7.11.6	V2 6058	Condensation Limitation	APP	APP	
7.12	V2 7084	Recreational Capabilities	N/A	N/A	
8.1.1	V2 8001	Volume Allocation	N/A	N/A	X
8.1.2	V2 8005	Functional Arrangement	N/A	N/A	
8.1.3	V2 8006	Interference	N/A	N/A	
8.2.1	V2 8007	Spatial and Interface Orientation	N/A	N/A	
8.2.2	V2 8010	Location Identifiers	N/A	N/A	
8.2.3	V2 8011	Location Aids	N/A	N/A	
8.3.1	V2 8013	Intravehicular Translation Paths	N/A	N/A	X
8.3.2	V2 8014	Emergency Escape Paths	N/A	N/A	X
8.3.3	V2 8020	Assisted Ingress and Egress Translation Path	N/A	N/A	X
8.3.4	V2 11005	EVA Translation Path Hazard Avoidance	N/A	N/A	X
8.4.1.1	V2 8022	Hatches, Hatch Covers, and Door Operation Without Tools	N/A	N/A	X
8.4.1.2	V2 8023	Unlatching Hatch Covers	N/A	N/A	X
8.4.1.3	V2 8024	Hatch Cover and Door Operating Times	N/A	N/A	X
8.4.1.4	V2 8025	Hatch Cover and Door Operating Force	N/A	N/A	X

Section	Rqmt #	Description	EVA	LEA/IVA	Interfaces
8.4.2.1	V2 8027	Hatch Size and Shape	N/A	N/A	X
8.4.2.2	V2 8028	Pressure Equalization across the Hatch	N/A	N/A	X
8.4.2.3	V2 8029	Visibility across the Hatch	N/A	N/A	X
8.4.3.1	V2 8030	Hatch Cover and Door Interference	N/A	N/A	X
8.4.3.2	V2 8031	Hatch Cover Closure and Latching Status Indication	N/A	N/A	
8.4.3.3	V2 8032	Hatch Cover Pressure Indication	N/A	N/A	
8.4.4	V2 8101	No Drag-Throughs			
8.4.5	V2 8032	Hatch Pressure Indication	N/A	N/A	
8.5.1	V2 8033	Restraints for Crew Tasks	N/A	APP	X
8.5.2	V2 8038	Restraint and Mobility Aid Standardization	N/A	N/A	X
8.5.3	V2 8040	Mobility Aid for Assisted Ingress and Egress	N/A	N/A	X
8.5.4	V2 8041	Unassisted Ingress, Egress, and Escape Mobility Aids	APP	APP	X
8.5.5	V2 8042	Mobility Aid Provision	N/A	N/A	X
8.5.6	V2 8102	Human Transport Vehicle Restraint Provision			
8.6.1	V2 8043	Window Provisioning	N/A	N/A	
8.6.2	V2 8045	Window Optical Properties	N/A	N/A	
8.6.3	V2 8049	Window Light Blocking	N/A	N/A	
8.6.4	V2 8050	Window Accessory Replacement/Operation without Tools	N/A	N/A	
8.7.1	V2 8051	Illumination Levels	APP	APP	
8.7.2	V2 8052	Exterior Lighting	APP	N/A	X
8.7.3	V2 8053	Emergency Lighting	N/A	N/A	X
8.7.4	V2 8059	Lighting Chromaticity	APP	APP	
8.7.5	V2 8060	Lighting Color Accuracy	APP	APP	
8.7.6	V2 8055	Physiological Effects of Light (Circadian Entrainment)	N/A	N/A	
8.7.7	V2 8056	Lighting Controls	APP	APP	
8.7.8	V2 8057	Lighting Adjustability	N/A	N/A	
8.7.9	V2 8058	Glare Prevention	APP	APP	
9.1.1	V2 9001	Crew Interface Commonality	APP	APP	
9.1.2	V2 9002	Differentiation	APP	APP	
9.1.3	V2 9003	Routine Operation	APP	APP	
9.2	V2 9004	Training Minimization	APP	APP	
9.3.1.1	V2 9101	Design for Crew Safety	APP	APP	
9.3.1.2	V2 9005	Mechanical Hazard	APP	APP	
9.3.1.3	V2 9006	Entrapment	APP	APP	
9.3.1.4	V2 9007	Potential Energy	APP	APP	
9.3.1.5	V2 9008	Protection from Projectiles and Structural Collapse	APP	APP	
9.3.1.6	V2 9009	Sharp Corners and Edges – Fixed	APP	APP	
9.3.1.7	V2 9010	Protection from Functionally Sharp Items	APP	APP	
9.3.1.8	V2 9011	Sharp Corners and Edges - Loose	APP	APP	
9.3.1.9	V2 9012	Burrs	APP	APP	
9.3.1.10	V2 9013	Pinch Points	APP	APP	
9.3.1.11	V2 9016	Equipment Handling	APP	APP	
9.3.1.2	V2 9102	Skin/Tissue Damage Temperature Limits			
9.3.1.3	V2 9103	Pain/Non- Disabling Injury Skin Temperature Limits			
9.3.3.1	V2 9017	Power Interruption	APP	APP	
9.3.3.2	V2 9018	Energized Status	APP	APP	
9.3.3.3	V2 9019	Nominal Physiological Electrical Current Limits	APP	APP	
9.3.3.4.1	V2 9020	Catastrophic Physiological Electrical Current Limits for All Circumstances	APP	APP	
9.3.3.4.2	V2 9021	Catastrophic Physiological Electrical Current Limits for Startle Reaction	APP	APP	

Section	Rqmt #	Description	EVA	LEA/IVA	Interfaces
9.3.3.5	V2 9022	Body Impedance for Voltage Calculations Utilizing Electrical Current Thresholds	APP	APP	
9.3.3.6	V2 9023	Leakage Currents – Equipment Designed for Human Contact	APP	APP	
9.3.4.1	V2 9024	Fluid/Gas Release	APP	APP	
9.3.4.2	V2 9025	Fluid/Gas Isolation	APP	APP	
9.3.4.3	V2 9026	Fluid/Gas Containment	APP	APP	
9.4.1	V2 9027	Protection	APP	APP	
9.4.2	V2 9028	Isolation of Crew from Spacecraft Equipment	N/A	N/A	
9.5.1	V2 9029	Hardware and Equipment Mounting and Installation	APP	APP	
9.5.2.1	V2 9030	Connector Spacing	APP	APP	
9.5.2.2	V2 9031	Connector Actuation without Tools	APP	APP	
9.5.2.3	V2 9032	Incorrect Mating, Demating Prevention	APP	APP	
9.5.2.4	V2 9033	Mating, Demating Hazards	APP	APP	
9.6.1	V2 9034	Cable Management	APP	APP	
9.6.2	V2 9035	Cable Identification	APP	APP	
9.7.1.1	V2 9036	Design for Maintenance	APP	APP	
9.7.1.2	V2 9037	Commercial Off-the-Shelf (COTS) Equipment Maintenance	N/A	N/A	
9.7.1.3	V2 9038	In-Flight Tool Set	APP	APP	
9.7.2.1	V2 9039	Maintenance Time	APP	APP	
9.7.2.2	V2 9042	Captive Fasteners	APP	APP	
9.7.2.3	V2 9043	Minimum Number of Fasteners - Item	APP	APP	
9.7.2.4	V2 9044	Minimum Variety of Fasteners - System	APP	APP	
9.7.3.1	V2 9045	Maintenance Item Location	APP	APP	
9.7.3.2	V2 9046	Check and Service Point Accessibility	APP	APP	
9.7.3.3	V2 9047	Maintenance Accommodation	APP	APP	
9.7.3.4	V2 9048	Visual Access for Maintenance	APP	APP	
9.7.3.5	V2 9050	Tool Clearance	N/A	N/A	X
9.7.4.1	V2 9051	Fault Detection	N/A	N/A	X
9.7.4.2	V2 9052	Failure Notification	APP	APP	
9.8.1.1.1	V2 9053	Protective Equipment	N/A	APP	
9.8.1.1.2	V2 9054	Protective Equipment Use	N/A	APP	
9.8.1.1.3	V2 9055	Protective Equipment Automation	N/A	APP	
9.8.1.2.1	V2 9056	Use of Hearing Protection	N/A	N/A	
9.8.1.2.2	V2 9057	Hearing Protection Provision	N/A	N/A	
9.8.1.2.3	V2 9058	Hearing Protection Interference	N/A	N/A	
9.8.2.1	V2 9059	Fire Detecting, Warning, and Extinguishing	N/A	N/A	X
9.8.2.2	V2 9060	Fire Protection System Health and Status	N/A	N/A	X
9.8.2.3	V2 9061	Fire Protection System Failure Alerting	N/A	N/A	X
9.8.2.4	V2 9062	Fire Protection System Activation	N/A	N/A	X
9.8.2.5	V2 9063	Portable Fire Extinguishers	N/A	N/A	X
9.8.3	V2 9064	Emergency Equipment Accessibility	N/A	APP	X
10.1.1.1	V2 10001	Crew Interface Usability	APP	APP	
10.1.1.2	V2 10002	Design-Induced Error	APP	APP	
10.1.1.3	V2 10003	Crew Interface Operability	APP	APP	
10.1.1.4	V2 5007	Cognitive Workload	APP	APP	
10.1.1.5	V2 10200	Physical Workload			
10.1.1.6	V2 5006	Situation Awareness (SA)	APP	APP	
10.1.2	V2 10004	Controllability and Maneuverability	N/A	N/A	X
10.1.3.1	V2 10005	Crew Interfaces Standardization	APP	APP	

Section	Rqmt #	Description	EVA	LEA/IVA	Interfaces
10.1.3.2	V2 10006	Operations Nomenclature Standardization	APP	APP	
10.1.3.3	V2 10007	Display Standards, Icon Library, and Labeling Plan	APP	APP	
10.1.3.4	V2 10008	Units of Measure	APP	APP	
10.1.3.5	V2 10009	Crew Interface Operations Standardization	APP	APP	
10.1.3.6	V2 10010	Consistent Layout	APP	APP	
10.1.3.7	V2 10011	Displays and Controls Commonality	APP	APP	
10.1.3.8	V2 10012	Consistent Procedures	APP	APP	
10.1.4.1	V2 10013	Display and Control Distinctions	APP	APP	
10.1.4.2	V2 10014	Syntax Distinction	APP	APP	
10.1.5.1	V2 10015	Use of Cognitive Aids	APP	APP	
10.1.5.2	V2 10016	Cue Saliency	APP	APP	
10.1.6.1	V2 10017	System Health and Status	APP	APP	
10.1.6.2	V2 10018	System Messages	APP	APP	
10.1.6.3	V2 10022	Stale, Missing, or Unavailable Data	APP	APP	
10.1.6.4	V2 10021	Control Feedback	APP	APP	
10.1.6.5	V2 10020	Maximum System Response Times	APP	APP	
10.1.6.6	V2 10200	LED Indicator Light Characteristics			
10.1.7.1	V2 10023	Current Procedure Step	APP	APP	
10.1.7.2	V2 10024	Completed Procedure Steps	APP	APP	
10.1.7.3	V2 10025	View of Procedure Steps	APP	APP	
10.1.7.4	V2 10026	Procedure Flexibility	APP	APP	
10.1.8.1	V2 10027	Inadvertent Operation Prevention	APP	APP	
10.1.8.2	V2 10028	Inadvertent Operation Recovery	APP	APP	
10.2.1.1	V2 10030	Display and Control Location and Design	APP	APP	
10.2.1.2	V2 10031	High Priority Displays and Controls	APP	APP	
10.2.2	V2 10032	Display and Control Grouping	APP	APP	
10.2.3.1	V2 10033	Display-Control Relationships	APP	APP	
10.2.3.2	V2 10034	Display and Control Movement Compatibility	APP	APP	
10.2.3.3	V2 10035	Display and Control Sequence of Use	APP	APP	
10.3.1.1	V2 10036	Display Identifying Features	APP	APP	
10.3.1.2	V2 10037	Display Area	APP	APP	
10.3.2.1	V2 10038	Display Interpretation	APP	APP	
10.3.2.2	V2 10039	Display Readability	APP	APP	
10.3.2.3	V2 10040	Display Information	APP	APP	
10.3.2.4	V2 10042	Display Information Flow	APP	APP	
10.3.2.5	V2 10043	Display Navigation	APP	APP	
10.3.2.6	V2 10044	Display Nomenclature	APP	APP	
10.3.2.7	V2 10045	Display Coding Redundancy	APP	APP	
10.3.2.8	V2 10046	Measurement Units	APP	APP	
10.3.3.1	V2 10047	Visual Display Legibility	APP	APP	
10.3.3.2	V2 10048	Visual Display Parameters	APP	APP	
10.3.3.3	V2 10049	Visual Display Character Parameters	APP	APP	
10.3.3.4	V2 10050	Display Font	APP	APP	
10.3.4.1.1	V2 10052	Intelligibility of Electronically Stored Speech Messages	APP	APP	
10.3.4.1.2	V2 10053	Sound Pressure Level	APP	APP	
10.3.4.1.3	V2 10054	Sound Distortion Level	APP	APP	
10.3.4.1.4	V2 10055	Distinguishable and Consistent Alarms	APP	APP	
10.3.4.2.1	V2 10056	Audio Display Sound Level	APP	APP	
10.3.4.2.2	V2 10057	Reverberation Time	N/A	APP	

Section	Rqmt #	Description	EVA	LEA/IVA	Interfaces
10.3.4.2.3	V2 10058	Frequency	APP	APP	
10.3.5.1	V2 10060	Label Provision	N/A	N/A	X
10.3.5.2	V2 10061	Label Standardization	APP	APP	
10.3.5.3	V2 10062	Label Display Requirements	APP	APP	
10.3.5.4	V2 10063	Label Location	APP	APP	
10.3.5.5	V2 10064	Label Categories	APP	APP	
10.3.5.6	V2 10065	Label Distinction	APP	APP	
10.3.5.7	V2 10066	Label Font Height	APP	APP	
10.4.1	V2 10067	Control Shape	APP	APP	
10.4.2.1	V2 10068	Control Identification	APP	APP	
10.4.2.2	V2 10069	Emergency Control Coding	APP	APP	
10.4.3.1	V2 10070	Control Size and Spacing	APP	APP	
10.4.3.2	V2 10071	Control Arrangement and Location	APP	APP	
10.4.3.3	V2 10072	Control Proximity	APP	APP	
10.4.3.4	V2 10073	Control Operation Supports and Restraints	N/A	N/A	X
10.4.4.1	V2 10074	Control Operating Characteristics	APP	APP	
10.4.4.2	V2 10075	Control Input-Response Compatibility	APP	APP	
10.4.4.3	V2 10076	Control Latency	APP	APP	
10.4.4.4	V2 10077	Control Resistive Force	APP	APP	
10.4.4.5	V2 10078	Detent Controls	APP	APP	
10.4.4.6	V2 10079	Stops Controls	APP	APP	
10.4.5	V2 10080	Command Confirmation	APP	APP	
10.4.6.1	V2 10081	Suited Control Operations	APP	APP	
10.4.6.2	V2 10082	Suited Control Spacing	APP	APP	
10.5.1	V2 10083	Communication System Design	APP	APP	
10.5.2	V2 10084	Communication Capability	APP	APP	
10.5.3.1	V2 10085	Communication Speech Levels	APP	APP	
10.5.3.2	V2 10086	Communication Operational Parameters	APP	APP	
10.5.3.3	V2 10087	Communication Environmental Parameters	APP	APP	
10.5.3.4	V2 10088	Communication Controls and Procedures	APP	APP	
10.5.3.5	V2 10089	Communication Transmitter and Receiver Configuration	APP	APP	
10.5.3.6	V2 10090	Audio Communications Quality	APP	APP	
10.5.3.7	V2 10091	Speech Intelligibility	APP	APP	
10.5.3.8	V2 10093	Private Audio Communication	N/A	N/A	X
10.5.4.1	V2 10094	Video Communications Visual Quality	APP	APP	
10.5.4.2	V2 10095	Video Communications Spatial Resolution	APP	APP	
10.5.4.3	V2 10096	Video Communications Temporal Resolution	APP	APP	
10.5.4.4	V2 10097	Video Communications Color and Intensity	APP	APP	
10.5.4.5	V2 10098	Video Communications Bit Rate	APP	APP	
10.5.4.6	V2 10099	Audio-Visual Lag Time	APP	APP	
10.6.1	V2 10100	Automated and Robotic System Provision	APP	APP	
10.6.2	V2 10101	Automated and Robotic System Safety	APP	APP	
10.6.3	V2 10102	Robotic Control Stations – Common and Consistent	N/A	N/A	X
10.6.4	V2 10104	Automation Levels	APP	APP	
10.6.5	V2 10105	Automation Level Status Indication	APP	APP	
10.6.6	V2 10106	Robotic System Status	N/A	N/A	X
10.6.7	V2 10108	Automated and Robotic System Operation – with Communication Limitations	APP	APP	
10.6.8	V2 10109	Automated and Robotic System Shutdown Capabilities	APP	APP	

Section	Rqmt #	Description	EVA	LEA/IVA	Interfaces
10.6.9	V2 10110	Automation and Robotics Override Capabilities	APP	APP	
10.6.10	V2 10112	Crew Interfaces to Robotic Systems - Frames of Reference	N/A	N/A	
10.7.1	V2 10113	Information Management Capabilities – Provision	APP	APP	
10.7.2.1	V2 10114	Visual and Audio Annunciations	APP	APP	
10.7.2.2	V2 10115	Automatic Set-Point Alerts	APP	APP	
10.7.2.3	V2 10116	Audio Annunciation Silencing	APP	APP	
10.7.2.4	V2 10117	Visual and Auditory Annunciation Failures	APP	APP	
10.7.2.5	V2 10118	Visual Alerts - Red	APP	APP	
10.7.2.6	V2 10119	Visual Alerts - Yellow	APP	APP	
10.7.3.1	V2 10120	Information Management Methods and Tools	APP	APP	
10.7.3.2	V2 10121	Information Management Standard Nomenclature	APP	APP	
10.7.3.3	V2 10122	Information Management Compatibility	APP	APP	
10.7.3.4	V2 10123	Information Management Operation Rate	APP	APP	
10.7.3.5	V2 10124	Information Management Data Provision	APP	APP	
10.7.3.6	V2 10125	Information Management Security	APP	APP	
10.7.3.7	V2 10126	Information Management Ground Access	APP	APP	
10.7.3.8	V2 10127	Information Capture and Transfer	PA	PA	X
10.7.3.9	V2 10128	Information Annotation	N/A	N/A	
10.7.3.10	V2 10129	Information Backup and Restoration	PA	PA	X
10.7.3.11	V2 10130	Alternative Information Sources	APP	APP	
10.7.3.12	V2 10131	Software System Recovery	APP	APP	X
11.1.1	V2 11001	Suited Donning and Doffing	APP	APP	
11.1.2.1	V2 11006	Suit Pressure Set-Points	APP	APP	
11.1.2.2	V2 11007	Suit Equilibrium Pressure	APP	APP	
11.1.2.3	V2 11009	Continuous Noise in Spacesuits	APP	APP	
11.1.2.4	V2 11010	EVA Suit Radiation Monitoring	APP	N/A	X
11.1.2.5	V2 11011	Suited Crewmember Heat Storage	APP	N/A	
11.1.3.1	V2 11013	Suited Body Waste Management – Provision	APP	APP	
11.1.3.2	V2 11028	EVA Suit Urine Collection	APP	N/A	
11.1.3.3	V2 11014	LEA Suit Urine Collection	N/A	APP	X
11.1.3.4	V2 11015	Suit Urine Collection per Day - Contingency	N/A	APP	X
11.1.3.5	V2 11016	Suit Feces Collection per Day – Contingency	N/A	APP	
11.1.3.6	V2 11017	Suit Isolation of Vomitus	APP	APP	X
11.1.4.1	V2 11018	Suited Field of Regard	APP	APP	X
11.1.4.2	V2 11019	Suit Helmet Optical Quality	APP	APP	
11.1.4.3	V2 11020	Suit Helmet Luminance Shielding	APP	APP	
11.1.4.4	V2 11021	Suit Helmet Visual Distortions	APP	APP	
11.1.4.5	V2 11022	Suit Helmet Displays	APP	APP	
11.1.5	V2 11023	Suit Information Management	APP	APP	X
11.1.6	V2 11100	Pressure Suits for Protection from Cabin Depressurization			
11.2.1	V2 11024	Ability to Work in Suits	APP	APP	
11.2.2	V2 11025	Suited Nutrition	APP	APP	X
11.2.3.1	V2 11029	LEA Suited Hydration	N/A	APP	X
11.2.3.2	V2 11030	EVA Suited Hydration	APP	N/A	X
11.2.4	V2 11027	Suited Medication Administration	PA	APP	X
11.2.5	V2 11031	Suited Relative Humidity	APP	APP	
11.2.6	V2 11032	LEA Suited Decompression Sickness Prevention Capability	N/A	APP	
11.3.1	V2 11033	Suited Thermal Control	APP	APP	
11.3.2	V2 11034	Suited Atmospheric Data Recording	APP	APP	X

Section	Rqmt #	Description	EVA	LEA/IVA	Interfaces
11.3.3	V2 11035	Suited Atmospheric Data Displaying	APP	APP	X
11.3.4	V2 11036	Suited Atmospheric Monitoring and Alerting	APP	APP	X
11.3.5	V2 11039	Nominal Spacesuit Carbon Dioxide Levels	APP	N/A	
11.4.1	V2 11037	EVA Suited Metabolic Rate Measurement	APP	N/A	X
11.4.2	V2 11038	EVA Suited Metabolic Rate Display	APP	APP	
11.5	V2 11101	Incapacitated Crew Rescue (ICR)			
12.1.1	V2 12003	System Assumptions			
12.1.2.1	V2 12004	Anthropometry, Biomechanics, Range of Motion, and Strength			
12.1.2.2	V2 12005	Protective Equipment			
12.1.2.3	V2 12006	Volume Accommodation			
12.1.2.4	V2 12007	Ground Processing – Induced Forces			
12.1.2.5	V2 12008	Systems Accessibility			
12.1.2.6	V2 12009	Tool Clearance			
12.1.3.1	V2 12010	Flight Hardware Differentiation			
12.1.3.2	V2 12011	Hardware Protection			
12.1.3.3	V2 12012	Mobility Aids			
12.1.3.4	V2 12013	Equipment Handling Design			
12.1.3.5	V2 12014	Inadvertent Operation Prevention			
12.1.3.6	V2 12015	Incorrect Installation Prevention			
12.1.3.7	V2 12016	Pre-Defined Tool Set			
12.1.3.8	V2 12017	Captive Fasteners			
12.1.3.9	V2 12018	Ground Processing Without Damage			
12.1.3.10	V2 12019	Replaceable Items			
12.1.3.11	V2 12020	Visual Access for Ground Processing			
12.1.3.12	V2 12021	Lighting			
12.1.3.13	V2 12022	Supplemental Systems			
12.1.3.14	V2 12023	Operational Consistency			
12.1.3.15	V2 12024	Restraints and Platforms			
12.1.3.16	V2 12025	System Feedback			
12.1.3.17	V2 12026	Stowage Access			
12.1.3.18	V2 12027	Flight Software Systems			
12.1.4.1	V2 12028	Sharp Edge and Burr Injury Prevention			
12.1.4.2	V2 12029	Pinch Point Prevention			
12.1.4.3	V2 12030	Hazard Controls			
12.1.4.4	V2 12031	System Safing for Ground Operations			
12.1.4.5	V2 12032	Contamination Controls			
12.1.4.6	V2 12033	Containment of Fluids and Gases			
12.1.4.7	V2 12034	Safe Weight Limit			
12.1.4.8	V2 12035	Safe Flight System Component Arrangement			
12.1.5.1	V2 12036	Connector Design and Spacing			
12.1.5.2	V2 12037	Connector Incorrect Mating Prevention			
12.1.6.1	V2 12038	Label Provisions			
12.1.6.2	V2 12039	Label Standardization			
12.1.6.3	V2 12040	Label Content			
12.1.6.4	V2 12041	Readable Label Positioning			
12.1.6.5	V2 12042	Non-Obstructive Labels			
12.2.1	V2 12043	Emergency Egress at the Launch Site			
12.2.2	V2 12044	Emergency Egress to Medical Care			
12.2.3	V2 12045	Nominal Timely Egress			

Section	Rqmt #	Description	EVA	LEA/IVA	Interfaces
12.2.4	V2 12046	Emergency Egress Acceleration Limits			

APPENDIX F

PHYSICAL CHARACTERISTICS AND CAPABILITIES DATA SETS

F.1 PURPOSE

A system designed for human use or habitation must accommodate the range of human characteristics and capabilities relevant to the system and operating environment for the NASA-defined crew population. The datasets provided include characteristics and capabilities for anthropometric dimensions, range of motion, strength, mass, volume, and surface area. The datasets and their supplemental information take into account human characteristics such as age, sex, and physical condition as well as mission characteristics such as clothing and suit pressurization.

The intent of the standards in Section 4 is to accommodate the entire potential user population, not just meet the criteria in the datasets provided, which provide the most frequently used values. Identification of a design criteria not provided in the tables needs coordination and concurrence from NASA Stakeholders. Each dataset may be tailored by NASA based on program or mission specific criteria.] Guidance on the evaluation of design for physical characteristics and capabilities can be found in NASA/TP-2014-218556, Human Integration Design Process (HIDP).

F.2 ANTHROPOMETRIC DIMENSIONS

The data in the tables are from the population in the 1988 Anthropometric Survey of US Army Personnel (ANSUR) (ref. Natick/TR-89/044), projected forward by NASA to 2015 to account for the expected small growth in the size of members of the US population. Note that for measurements that include the length of the spine, 3% of stature (for standing measurements) or 6% of seated height (for sitting measurements) must be added to allow for spinal elongation due to micro-gravity exposure. Additional information on the derivation of 3% and 6% values can be found in NASA/SP-2010-3407 Revision 1, Human Integration Design Handbook (HIDH). These dimensions must be considered in light of garments, space adaptive postures and personal protective equipment that is expected to be used per task and environmental conditions.

F.2.1 References

Gordon, C.C., Churchill, T., Clauser, C.E., Bradtmiller, B., McConville, J.T., Tebbetts, I., Walker, R.A. (1989). 1988 Anthropometric survey of U.S. army personnel: methods and summary statistics. NATICK/TR-89/044, United States Army Natick Research, Development and Engineering Center, Massachusetts.

Table 40—Anthropometric Dimensions

Critical Dimension	Application Example	Minimal Clothing	
		Min (cm, (in))	Max (cm, (in))
Stature, Standing[3]	Maximum vertical clearance	148.6 (58.5)	194.6 (76.6)
Sitting Height[2]	Vertical seating clearance	77.7 (30.6)	101.3 (39.9)
Eye Height, Sitting[2]	Placement of panels to be within line-of-sight	66.5 (26.2)	88.9 (35.0)
Acromial Height, Sitting[2]	Top of seatback	49.5 (19.5)	68.1 (26.8)
Thigh Clearance, Sitting	Placement of objects that may be overlap (panels, control wheel, etc.)	13.0 (5.1)	20.1 (7.9)
Knee Height, Sitting	Height of panels in front of subject	45.5 (17.9)	63.5 (25.0)
Popliteal Height, Sitting	Height of seat pan	33.0 (13.0)	50.0 (19.7)
Wrist Height, Sitting (with arm to the side)	Downward reach of subject	39.6 (15.6)	54.6 (21.5)
Biacromial Breadth	Placement of restraint straps	32.3 (12.7)	44.5 (17.5)
Bideltoid Breadth	Width of seatback	37.8 (14.9)	56.1 (22.1)
Forearm-Forearm breadth	Side clearance envelope, possible seatback width	38.9 (15.3)	66.0 (26.0)
Hip Breadth, Sitting[1]	Width of seat pan	31.5 (12.4)	46.5 (18.3)
Buttock-Popliteal Length, Sitting	Length of seat pan	42.2 (16.6)	57.2 (22.5)
Buttock-Knee Length, Sitting	Placement of panels in front of subject	52.1 (20.5)	69.9 (27.5)
Foot Length, Sitting	Rudder pedal design, foot clearance	21.6 (8.5)	30.5 (12.0)
Thumb Tip Reach, Sitting	Placement of control panels, maximum reach	65.0 (25.6)	90.9 (35.8)
Shoulder to Elbow Length	Placement and adjustability of hand controls; Vehicle reach access	29.6 (11.6)	41.9 (16.5)
Elbow to Center of Grip Length	Placement and adjustability of hand controls; Vehicle reach access	28.7 (11.3)	40.8 (16.1)
Hip Breadth, Standing[1]	Clearance while traversing and egressing the vehicle	29.8 (11.7)	40.6 (16.0)
Bust Depth, Standing	Clearance while traversing and egressing the vehicle	19.1 (7.5)	30.2 (11.9)
Waist depth	Placement and length of restraint straps	15.0 (5.9)	30.0 (11.8)
Hand Length	Placement and adjustability of hand controls; Vehicle reach access	15.8 (6.2)	22.1 (8.7)
Elbow to Wrist length	Placement and adjustability of hand controls; Vehicle reach access	22.5 (8.9)	33.1 (13.0)
Cervical Height, Standing[3]	Posture based clearance while traversing and egressing the vehicle	127.7 (50.3)	169.8 (66.9)
Trochanteric Height	Posture based clearance while traversing and egressing the vehicle	75.2 (29.6)	105.4 (41.5)
Ankle Height	Posture based clearance while traversing and egressing the vehicle	4.8 (1.9)	8.1 (3.2)
Acromion (Shoulder) Height, Standing[3]	Posture based clearance while traversing and egressing the vehicle	120.4 (47.4)	161.8 (63.7)

[1]*The largest female hip breadth is larger than the largest male hip breadth, and the smallest male hip breadth is smaller than the smallest female hip breadth; therefore, male data are used for the Min dimension, and female data are used for the Max dimension.*

[2] For measurements that include the length of the spine in sitting postures, 6% of the sitting measurement must be added to allow for spinal elongation due to micro-gravity exposure. Additional information on the derivation 6% values can be found in NASA/SP-2010-3407 Revision 1, Human Integration Design Handbook (HIDH).
[3] For measurements that include the length of the spine in standing postures, 3% the standing measurement must be added to allow for spinal elongation due to micro-gravity exposure. Additional information on the derivation 3% values can be found in NASA/SP-2010-3407 Revision 1, Human Integration Design Handbook (HIDH).

F.3 RANGE OF MOTION

The ranges of motion to be accommodated for crewmembers were collected in 1 g conditions as part of a 2007/2008 study in the NASA JSC Anthropometry and Biomechanics Facility. The values represented in these tables show the level of mobility that was needed to perform a variety of relevant functional tasks. These numbers do not necessarily indicate maximum level of mobility possible in a given configuration.

Table 41, Unsuited Range of Motion, provides several joint measures that were present in old versions of this table but were not reinvestigated as a part of the 2007/2008 mobility study. These values are specifically called out when listed in the table.

Tables 42 and 43 provide Range of Motion (ROM) for several joint measures under unpressurized and pressurized suit conditions. It should be noted that since pressurization causes severe restrictions to range of motion, no pressurized ROM for a LEA type suit is provided. Hence, pressurized ROM data are applicable only for an EVA type suit.

F.3.1 References

“1979 Study” refers to data from SP-2-86L-064 Thornton, W, and Jackson, J. Anthropometric Study of Astronaut Candidates, 1979 to 1980, (Unpublished Data) NASA-JSC.

Table 41—Unsuited Range of Motion

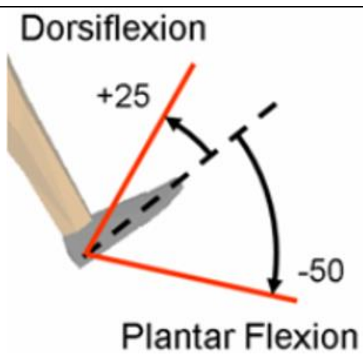
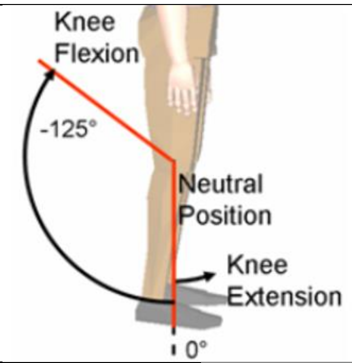
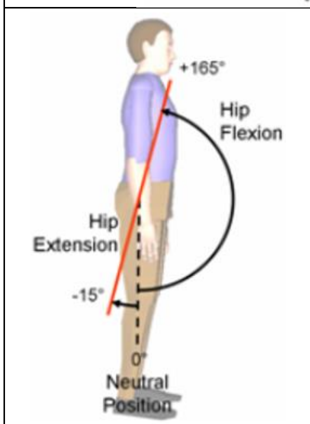
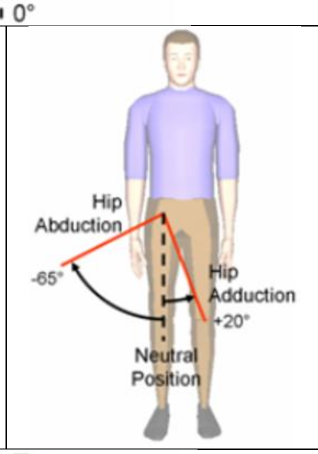
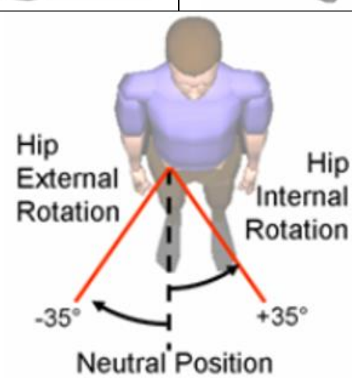
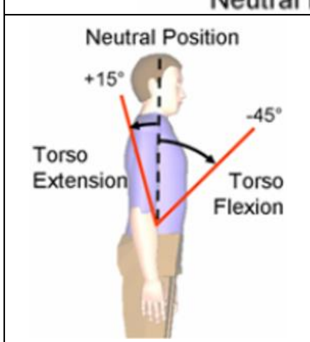
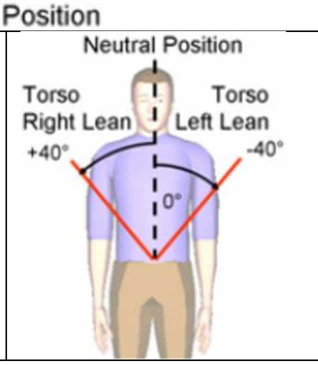
Diagram	Anatomy	Unsuited ROM (in degrees)	
	Ankle	Dorsiflexion	Plantar Flex
		25	-50
	Knee	Flexion	Extension

Diagram	Anatomy	Unsuited ROM (in degrees)	
		-125	0
 	Hip	Flexion	Extension
		165	-15
		Abduction	Adduction
		-65	20
		Internal Rotation	External Rotation
		35	-35
 	Torso	Flexion	Extension
		-45	15
		Right Lean	Left Lean
		40	-40

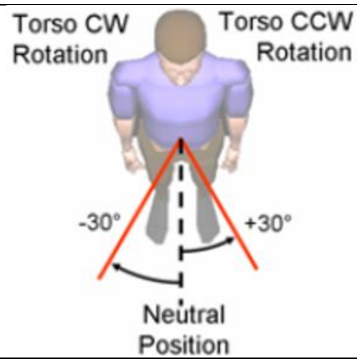
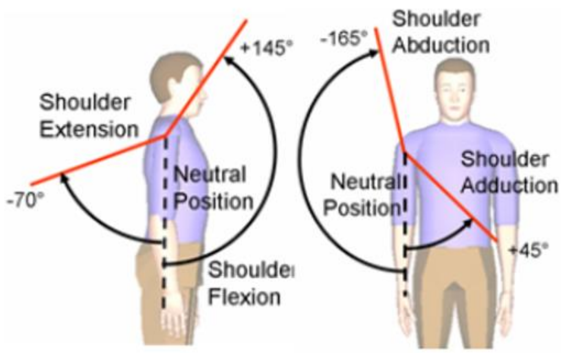
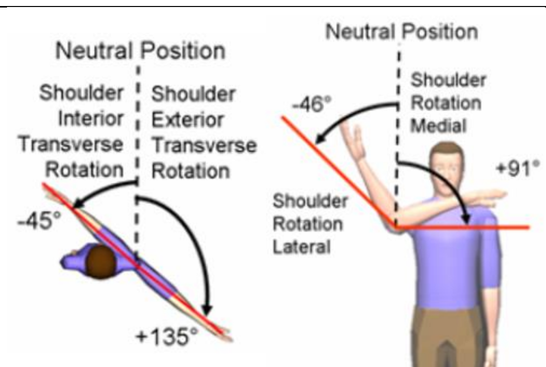
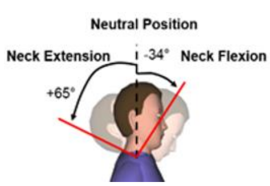
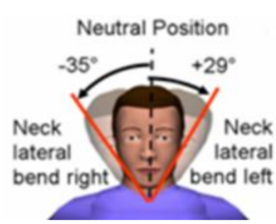
<table>
<tr><th colspan="2">Diagram</th><th>Anatomy</th><th colspan="2">Unsuited ROM (in degrees)</th></tr>
<tr><td colspan="2" rowspan="2">
</td><td rowspan="2"></td><td>CCW</td><td>CW</td></tr>
<tr><td>30</td><td>-30</td></tr>
<tr><td colspan="2" rowspan="4">
</td><td rowspan="4">Shoulder</td><td>Flexion</td><td>Extension</td></tr>
<tr><td>145</td><td>-70</td></tr>
<tr><td>Abduction</td><td>Adduction</td></tr>
<tr><td>-165</td><td>45</td></tr>
<tr><td colspan="2" rowspan="4">
</td><td rowspan="4">Shoulder 1979 Study</td><td>Interior Transverse Rotation</td><td>Exterior Transverse Rotation</td></tr>
<tr><td>-45</td><td>135</td></tr>
<tr><td>Lateral</td><td>Medial</td></tr>
<tr><td>-46</td><td>91</td></tr>
<tr><td rowspan="4">
</td><td rowspan="4">
</td><td rowspan="5">Neck 1979 Study</td><td>Flex</td><td>Ex</td></tr>
<tr><td>-34</td><td>65</td></tr>
<tr><td>Bend Right</td><td>Bend Left</td></tr>
<tr><td>-35</td><td>29</td></tr>
<tr><td colspan="2"></td><td>Rotation Right</td><td>Rotation Left</td></tr>
</table>

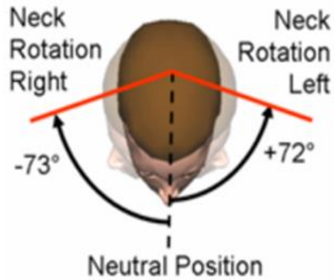
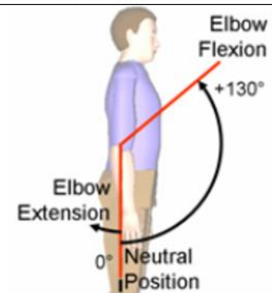
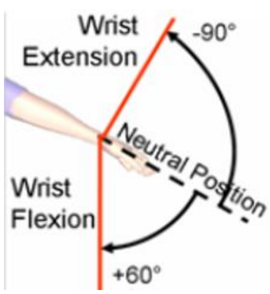
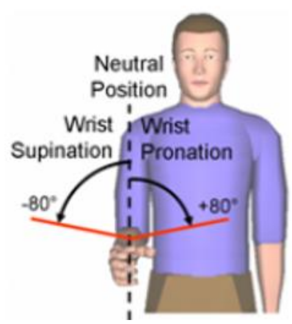
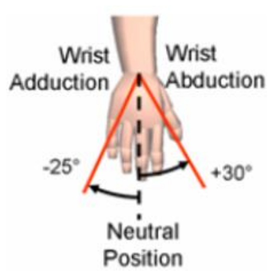
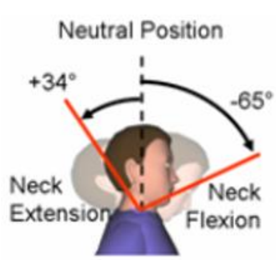
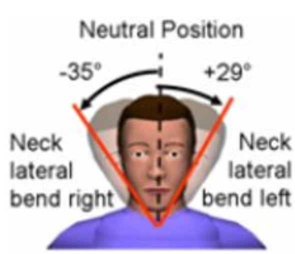
Diagram	Anatomy	Unsuited ROM (in degrees)	
		-73	72
	Elbow	Flexion	Extension
		130	0
 	Wrist	Extension	Flexion
		-90	60
		Abduction (Radial Deviation)	Adduction (Ulnar Deviation)
		30	-25
		Supination	Pronation
		-80	80
 	Neck 1979 Study	Flex	Ex
		-65	34
		Bend Right	Bend Left
		-35	29

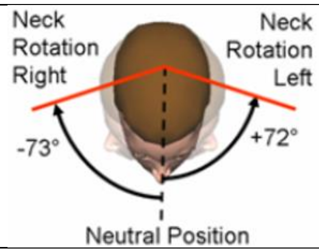
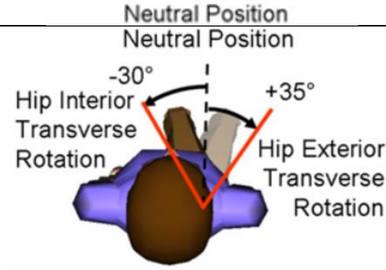
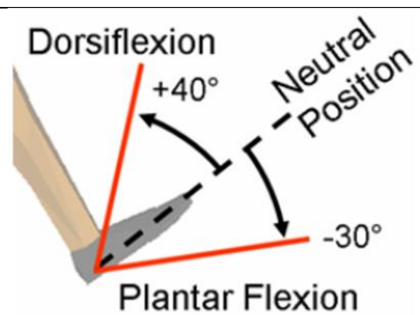
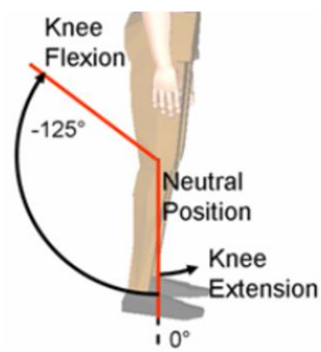
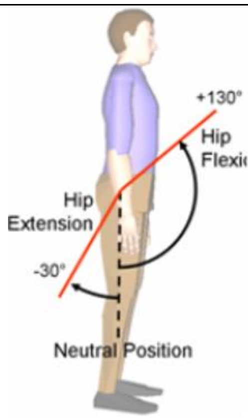
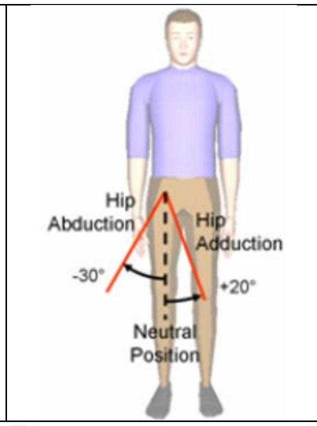
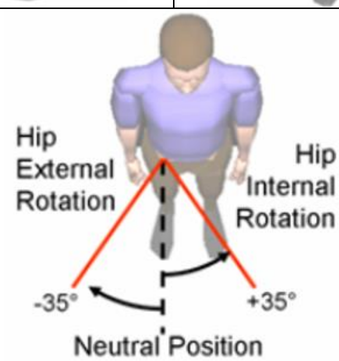
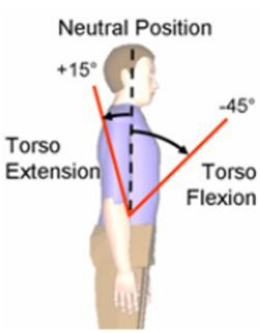
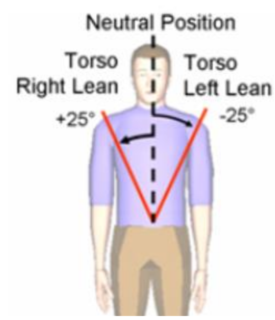
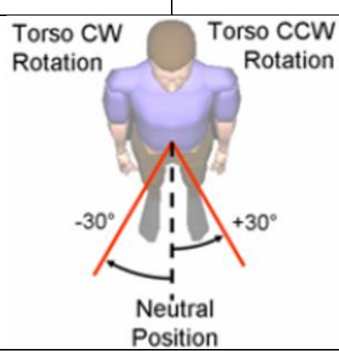
Diagram	Anatomy	Unsuited ROM (in degrees)	
		Rot R	Rot L
		-73	72
	Hip 1979 Study	Interior Transverse Rotation	Exterior Transverse Rotation
		-30	35

Table 42—Suited/Unpressurized Range of Motion

Diagram		Anatomy	Suited Unpressurized ROM (in degrees)	
		Ankle	Dorsiflexion	Plantar Flex
			40	-30
		Knee	Flexion	Extension
			-125	0
		Hip	Flexion	Extension

<table>
<tr><th colspan="2">Diagram</th><th>Anatomy</th><th colspan="2">Suited Unpressurized ROM (in degrees)</th></tr>
<tr><td rowspan="3">
</td><td rowspan="3">
</td><td rowspan="5"></td><td>130</td><td>-30</td></tr>
<tr><td>Abduction</td><td>Adduction</td></tr>
<tr><td>-30</td><td>20</td></tr>
<tr><td colspan="2" rowspan="2">
</td><td>Internal Rotation</td><td>External Rotation</td></tr>
<tr><td>35</td><td>-35</td></tr>
<tr><td rowspan="4">
</td><td rowspan="4">
</td><td rowspan="6">Torso</td><td>Flexion</td><td>Extension</td></tr>
<tr><td>-45</td><td>15</td></tr>
<tr><td>Right Lean</td><td>Left Lean</td></tr>
<tr><td>25</td><td>-25</td></tr>
<tr><td colspan="2" rowspan="2">
</td><td>CCW</td><td>CW</td></tr>
<tr><td>30</td><td>-30</td></tr>
</table>

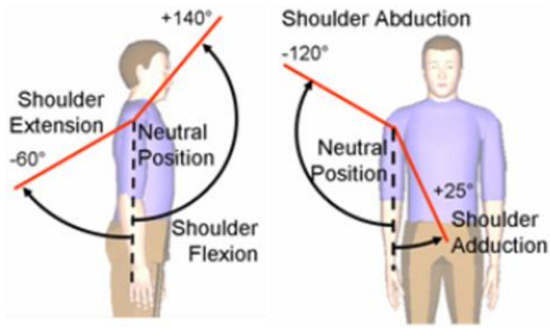
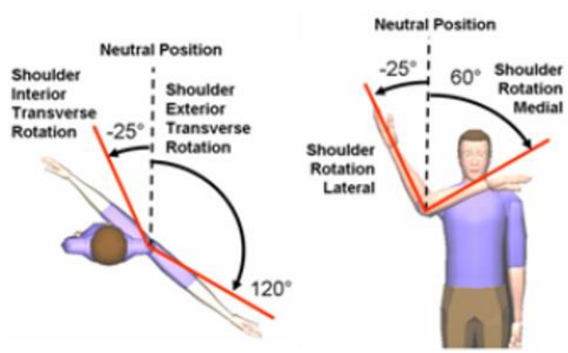
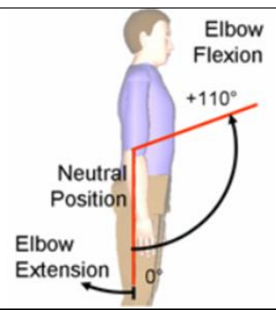
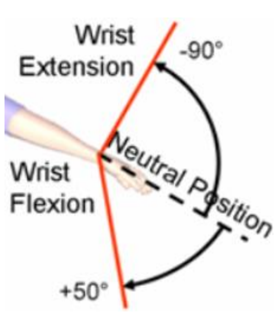
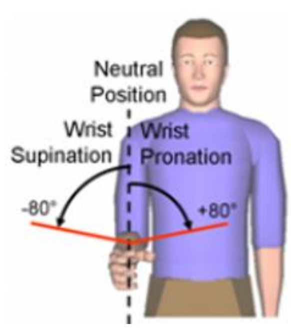
<table>
<tr><th colspan="2">Diagram</th><th>Anatomy</th><th colspan="2">Suited Unpressurized ROM (in degrees)</th></tr>
<tr><td colspan="2" rowspan="4">
</td><td rowspan="4">Shoulder</td><td>Flexion</td><td>Extension</td></tr>
<tr><td>140</td><td>-60</td></tr>
<tr><td>Abduction</td><td>Adduction</td></tr>
<tr><td>-120</td><td>25</td></tr>
<tr><td colspan="2" rowspan="4">
</td><td rowspan="4">Addt’l Shoulder</td><td>Interior Transverse Rotation</td><td>Exterior Transverse Rotation</td></tr>
<tr><td>-25</td><td>120</td></tr>
<tr><td>Lateral</td><td>Medial</td></tr>
<tr><td>-25</td><td>60</td></tr>
<tr><td colspan="2" rowspan="2">
</td><td rowspan="2">Elbow</td><td>Flexion</td><td>Extension</td></tr>
<tr><td>110</td><td>0</td></tr>
<tr><td rowspan="3">
</td><td rowspan="4">
</td><td rowspan="4">Wrist</td><td>Extension</td><td>Flexion</td></tr>
<tr><td>-90</td><td>50</td></tr>
<tr><td>Abduction (Radial Deviation)</td><td>Adduction (Ulnar Deviation)</td></tr>
<tr><td></td><td>30</td><td>-30</td></tr>
</table>

Diagram		**Anatomy**	**Suited Unpressurized ROM (in degrees)**	
			Supination	Pronation
			-80	80

Table 43—Suited/Pressurized Range of Motion

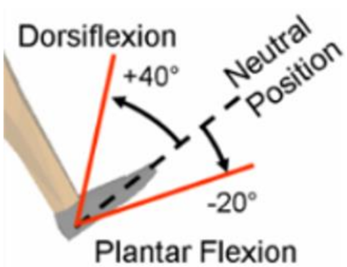
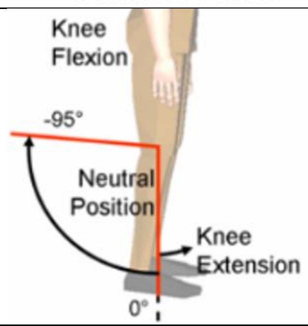
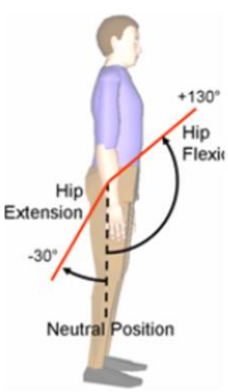
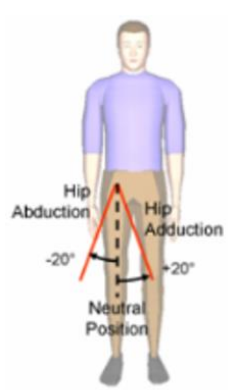
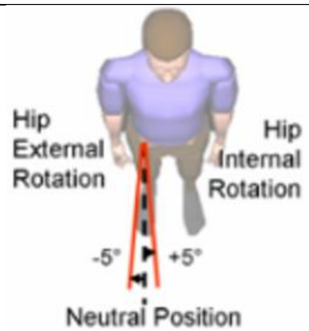
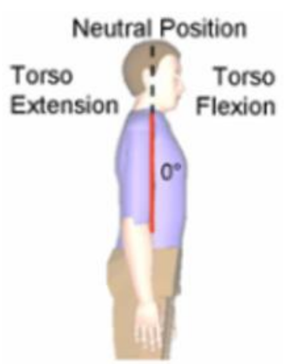
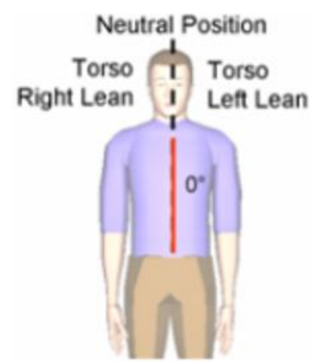
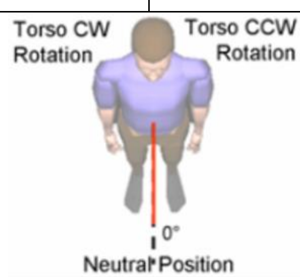
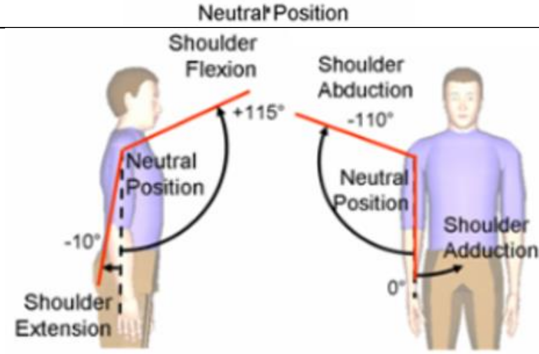
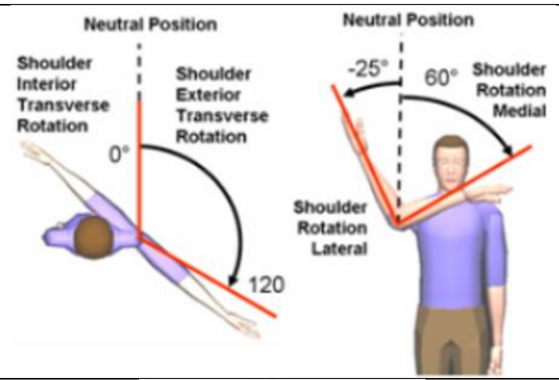
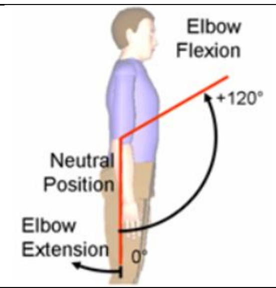
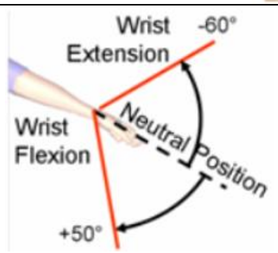
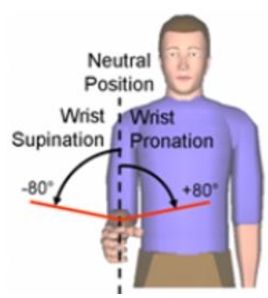
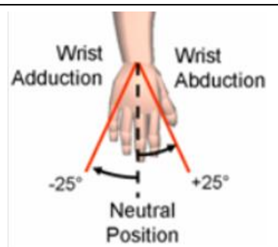
Diagram		**Anatomy**	**Suited Unpressurized ROM (in degrees)**	
		Ankle	Dorsiflexion	Plantar Flex
			40	-20
		Knee	Flexion	Extension
			-95	0
		Hip	Flexion	Extension
			130	-30
			Abduction	Adduction
			-20	20

Diagram	Anatomy	Suited Unpressurized ROM (in degrees)	
		Internal Rotation	External Rotation
		5	-5
 	Torso	Flexion	Extension
		0	0
		Right Lean	Left Lean
		0	0
		CCW	CW
		0	0
	Shoulder	Flexion	Extension
		115	-10
		Abduction	Adduction
		-110	0
	Addt'l Shoulder	Interior Transverse Rotation	Exterior Transverse Rotation
		0	120

<table>
<tr><th colspan="2">Diagram</th><th>Anatomy</th><th colspan="2">Suited Unpressurized ROM (in degrees)</th></tr>
<tr><td colspan="2" rowspan="2">
</td><td rowspan="2"></td><td>Lateral</td><td>Medial</td></tr>
<tr><td>-25</td><td>60</td></tr>
<tr><td colspan="2" rowspan="2">
</td><td rowspan="2">Elbow</td><td>Flexion</td><td>Extension</td></tr>
<tr><td>120</td><td>0</td></tr>
<tr><td rowspan="2">
</td><td rowspan="6">
</td><td rowspan="6">Wrist</td><td>Extension</td><td>Flexion</td></tr>
<tr><td>-60</td><td>50</td></tr>
<tr><td rowspan="4">
</td><td>Abduction (Radial Deviation)</td><td>Adduction (Ulnar Deviation)</td></tr>
<tr><td>25</td><td>-25</td></tr>
<tr><td>Supination</td><td>Pronation</td></tr>
<tr><td>-80</td><td>80</td></tr>
</table>

F.4 BODY SURFACE AREA

Whole body surface areas were computed by using a simple linear regression equation developed by Gehan and George (1970), as applied to the NASA dataset. Anthropometric data within the NASA dataset is for an age truncated subset of participants from the 1988 Anthropometric Survey of the U.S. Army (ANSUR) projected forward to the year 2015. This database is considered the most representative dataset for the American astronaut population.

Data for all members of the NASA dataset (both male and female) was entered into the equations to calculate whole-body surface areas. From the resulting values, mean and standard deviation for each gender were used to calculate the 1st percentile female and 99th percentile male whole-body surface area values. The 1st percentile value represents the minimum and the 99th percentile value represents the maximum in Table F.4.1, Body Surface Area of a Crewmember.

F.4.2 References

Gehan, E.A., & George, S.L. (1970). Estimation of human body surface area from height and weight. Cancer Chemotherapy Reports, 54, 225-235.

Table 44—Body Surface Area of a Crewmember

Crewmember Body Surface Area (cm^2, (in^2))	
Minimum	13,831 (2,144)
Maximum	24,282 (3,764)

F.5 BODY MASS

Crewmember whole-body mass, body-segment mass, center of mass location, and moment of inertia data are provided in Appendix F-4.

The anatomical axis system is based on skeletal landmarks and provides a consistent reference for the principal axes system and the center of volume/mass independent of body-segment orientation as described in McConville et al. (1980) and Young et al. (1983). The principal axis of inertia originates at the center of volume/mass.

Regression equations from McConville et al. (1980) and Young et al. (1983) were used to compute the Body-Segment Properties (BSP); however, because the sample sizes in these two studies were relatively small (31 and 46 subjects, respectively), this document uses data from the ANSUR database for input into the regression equations.

The regression equations from the McConville et al. (1980) and Young et al. (1983) studies were used in their most simple form, which uses only the stature and weight of the subject to calculate the volume and moments of inertia. A Matlab code was written to identify all females with a small stature (based on the female data only) and all males with a large stature (based on the male data only) in the ANSUR database; from this extracted data, the lightest female and heaviest male were identified. These values were then used in the regression equations to compute the BSP. McConville and Young did not generate regression equations to predict all BSP presented in this report; however, presented below is a description and reasoning (based on the available data) of how each BSP presented here was generated.

For tables Whole-Body Mass of Crewmember, Body-Segment Mass Properties for the Male and Female Crewmember, and Whole-Body Center of Mass Location of the Male and Female Crewmember, minimum values correspond to a small female in mass, and maximum values correspond to a large male in mass, respectively. These values are considered to be representative of those for a small female and a large male crewmember, respectively.

F.5.1 Whole-Body Mass

Regressions equations from the McConville et al. (1980) and Young et al. (1983) studies were used to compute the whole-body volume. Whole-body mass was calculated by assuming the density of the human flesh was homogeneous; a density value of 1 g/cm^3 was used. With a value of unity for the density, the mass values are numerically equal to their corresponding volume values.

F.5.2 Whole Body and Segments Center of Mass

Assuming that the human flesh was homogeneous, it can also be assumed that the center of volume is at the center of mass location. McConville et al. (1980) and Young et al. (1983) provided ranges for the location of the center of volume for the male and female, respectively, in each study. Because regression equations were not given for the center of volume, the range values from the McConville et al. (1980) and Young et al. (1983) studies were used here. Specific values for the locations of the center of mass with respect to the anatomical axes were taken from each study to form the range; specifically, the upper range was set by the male upper range, and the lower range was set by the female lower range.

F.5.3 Whole Body Moments of Inertia

Moments of inertia regression equations from the McConville et al. (1980) and Young et al. (1983) studies were used.

F.5.4 Segment Mass

Regressions equations from the McConville et al. (1980) and Young et al. (1983) studies were used to compute the segment volume. Segment mass was calculated by assuming the density of the human flesh was homogeneous; a density value of 1 g/cm^3 was used. With a value of unity for the density, the mass values are numerically equal to their corresponding volume values.

F.5.5 Segment Moments of Inertia

Regression equations from the McConville et al. (1980) and Young et al. (1983) studies were used to compute the moments of inertia. The moments of inertia presented are those about the principal axes Xp, Yp, and Zp.

F.5.6 References

McConville, J.T., Churchill, T.D., Kaleps, I., Cuzzi, J., (1980). Anthropometric relationships of body and body segment moments of inertia. AFAMRL-TR-80-119, Wright-Patterson Air Force Base, Ohio.

Young, J.W., Chandler, R.F., Snow, C.C., Robinette, K.M., Zenner, G.F., Lofberg, M.S. (1983). Anthropometrics and mass distribution characteristics of the adult female. FAA-AM-83-16, Revised Edition, FAA Civil Aeromedical Institute, Oklahoma City, Oklahoma.

Table 45—Whole Body Mass, Unsuited

Unsuited Crewmember Body Mass (kg, (lb))	
Minimum	42.64 (94)
Maximum	110.22 (243)
Data are projected to 2015	

Table 46—Body Segment Mass of a Crewmember, Unsuited

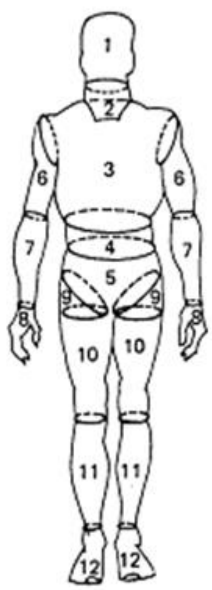
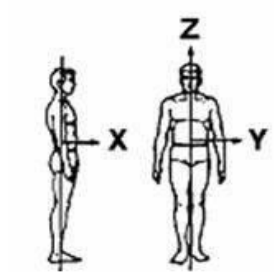
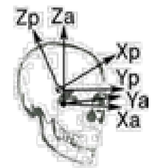
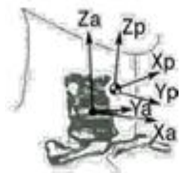
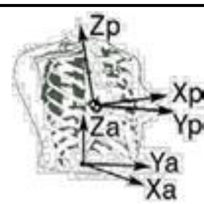
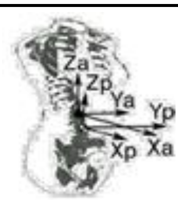
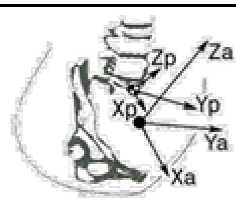
	Segment	Mass (kg, (lb))	
		Minimum	Maximum
	Head (1)	2.99 (6.59)	5.03 (11.08)
	Neck (2)	0.49 (1.08)	1.39 (3.07)
	Thorax (3)	11.35 (25.02)	34.33 (75.69)
	Abdomen (4)	2.14 (4.72)	3.25 (7.16)
	Pelvis (5)	5.62 (12.40)	16.46 (36.29)
	Upper Arm (6)	0.91 (2.00)	2.74 (6.04)
	Forearm (7)	0.59 (1.29)	1.86 (4.09)
	Hand (8)	0.24 (0.52)	0.66 (1.45)
	Hip Flap (9)	2.22 (4.90)	4.79 (10.55)
	Thigh minus Hip Flap (10)	3.86 (8.12)	8.48 (18.69)
	Calf (11)	1.94 (4.28)	5.11 (11.27)
	Foot (12)	0.44 (0.98)	1.26 (2.77)
	Torso (5 + 4 + 3)	19.11 (42.13)	54.05 (119.15)
	Thigh (9 + 10)	5.91 (13.03)	13.26 (29.24)
	Forearm Plus Hand (7 + 8)	0.82 (1.81)	2.51 (5.54)
Data are projected forward to 2015.			

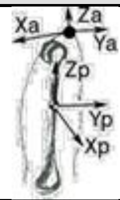
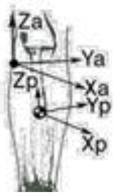
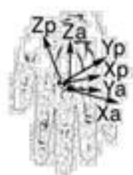
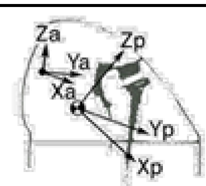
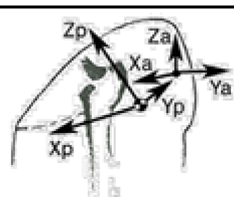
Table 47—Whole Body Center of Mass Location

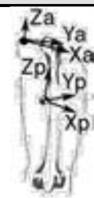
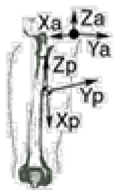
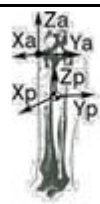
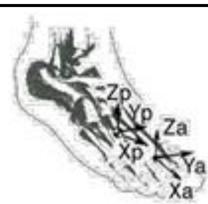
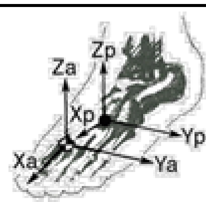


Dimension	Min (cm, (in))	Max (cm, (in))
L (Xa)	-15.27 (-6.01)	-6.40 (-2.52)
L (Ya)	-1.22 (-0.48)	0.97 (0.38)
L (Za)	-3.81 (-1.50)	8.15 (3.21)

Table 48—Body-Segment Center of Mass Location of the Crewmember, Unsuited

Segment		Anatomical Axis	Min (cm, (in))	Max (cm, (in))
Head		Xa	-2.44 (-0.96)	0.53 (0.21)
		Ya	-0.61 (-0.24)	0.61 (0.24)
		Za	2.24 (0.88)	4.04 (1.59)
Neck		Xa	3.40 (1.34)	7.32 (2.88)
		Ya	-0.56 (-0.22)	0.58 (0.23)
		Za	2.92 (1.15)	6.05 (2.38)
Thorax		Xa	3.76 (1.48)	7.06 (2.78)
		Ya	-0.81 (-0.32)	0.48 (0.19)
		Za	13.44 (5.29)	21.97 (8.65)
Abdomen		Xa	-1.47 (-0.58)	1.55 (0.61)
		Ya	-1.65 (-0.65)	2.26 (0.89)
		Za	-4.85 (-1.91)	-1.14 (-0.45)
Pelvis		Xa	-12.17 (-4.79)	-6.96 (-2.74)
		Ya	-1.32 (-0.52)	0.74 (0.29)
		Za	-0.76 (-0.30)	5.18 (2.04)
Torso		Xa	-10.41 (-4.1)	2.49 (0.98)
		Ya	-1.52 (-0.60)	1.73 (0.68)
		Za	16.33 (6.43)	25.60 (10.08)
Right upper arm		Xa	-0.71 (-0.28)	-0.91 (-0.36)
		Ya	1.85 (0.73)	-2.29 (-0.90)
		Za	-18.59 (-7.32)	-14.27 (-5.62)
Left upper arm		Xa	-0.64 (-0.25)	2.59 (1.02)
		Ya	-3.68 (-1.45)	-1.80 (-0.71)

Segment		Anatomical Axis	Min (cm, (in))	Max (cm, (in))
		Za	-18.72 (-7.37)	-14.33 (-5.64)
Right forearm		Xa	1.02 (0.40)	0.08 (0.03)
		Ya	-2.11 (-0.83)	4.14 (1.63)
		Za	-9.86 (-3.88)	-8.86 (-3.49)
Left forearm		Xa	1.17 (0.46)	0.13 (0.05)
		Ya	-0.23 (-0.09)	-2.44 (-0.96)
		Za	-9.86 (-3.88)	-9.07 (-3.57)
Right hand		Xa	-0.53 (-0.21)	0.03 (0.01)
		Ya	0.43 (0.17)	0.13 (0.05)
		Za	0.71 (0.28)	1.93 (0.76)
Left hand		Xa	-0.71 (-0.28)	-0.23 (-0.09)
		Ya	-1.35 (-0.53)	0.89 (0.35)
		Za	0.84 (0.33)	2.03 (0.80)
Right hip flap		Xa	-7.77 (-3.06)	1.70 (0.67)
		Ya	5.66 (2.23)	7.37 (2.90)
		Za	-6.73 (-2.65)	-6.05 (-2.38)
Left hip flap		Xa	-8.20 (-3.23)	2.41 (0.95)
		Ya	-10.67 (-4.2)	-5.18 (-2.04)
		Za	-6.96 (-2.74)	-6.20 (-2.44)
Right thigh minus flap		Xa	-3.28 (-1.29)	2.36 (0.93)
		Ya	5.18 (2.04)	8.38 (3.30)

Segment		Anatomical Axis	Min (cm, (in))	Max (cm, (in))
		Za	-24.84 (-9.78)	-23.34 (-9.19)
Left thigh minus flap		Xa	3.10 (1.22)	2.21 (0.87)
		Ya	-9.60 (-3.78)	-5.28 (-2.08)
		Za	-24.87 (-9.79)	-23.62 (-9.30)
Right calf		Xa	-4.24 (-1.67)	-0.10 (-0.04)
		Ya	-6.38 (-2.51)	-4.85 (-1.91)
		Za	-16.18 (-6.37)	-12.01 (-4.73)
Left calf		Xa	-4.34 (-1.71)	0.69 (0.27)
		Ya	4.04 (1.59)	6.83 (2.69)
		Za	-16.00 (-6.30)	-12.32 (-4.85)
Right foot		Xa	-8.51 (-3.35)	-6.63 (-2.61)
		Ya	-0.28 (-0.11)	0.43 (0.17)
		Za	0.46 (0.18)	-0.05 (-0.02)
Left foot		Xa	-8.71 (-3.43)	-6.48 (-2.55)
		Ya	-0.86 (-0.34)	0.89 (0.35)
		Za	0.33 (0.13)	-0.10 (-0.04)
Right thigh		Xa	-4.88 (-1.92)	2.11 (0.83)
		Ya	5.64 (2.22)	8.00 (3.15)
		Za	-17.55 (-6.91)	-17.55 (-6.91)
Left thigh		Xa	-4.75 (-1.87)	2.29 (0.90)
		Ya	-9.65 (-3.80)	-5.26 (-2.07)

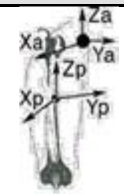
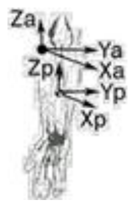
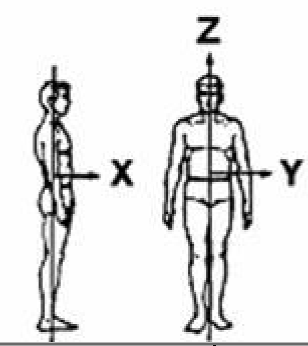
Segment		Anatomical Axis	Min (cm, (in))	Max (cm, (in))
		Za	-17.91 (-7.05)	-17.83 (-7.02)
Right forearm plus hand		Xa	0.43 (0.17)	-0.36 (-0.14)
		Ya	-2.29 (-0.90)	4.52 (1.78)
		Za	-15.54 (-6.12)	-14.99 (-5.9)
Left forearm plus hand		Xa	0.43 (0.17)	0
		Ya	0.79 (0.31)	-2.82 (-1.11)
		Za	-15.37 (-6.05)	15.01 (-5.91)

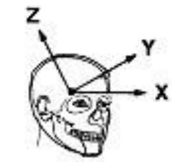
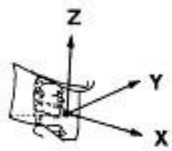
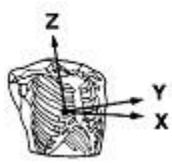
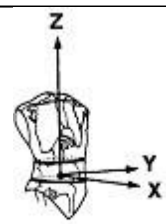
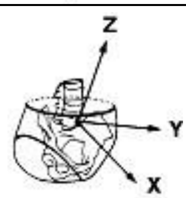
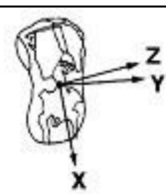
Table 49—Whole Body Moment of Inertia of the Crewmember, Unsuited

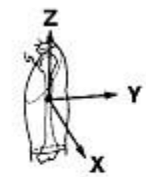
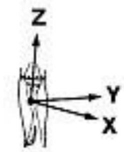
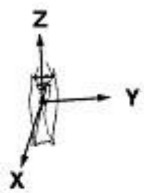
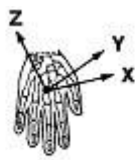
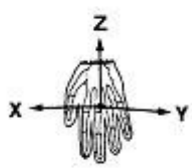
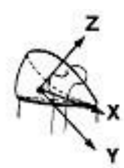
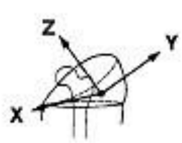


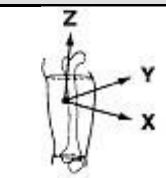
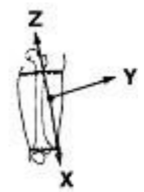
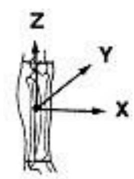
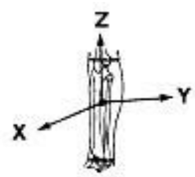
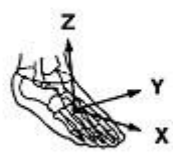
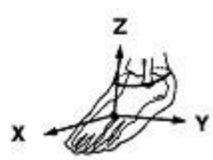
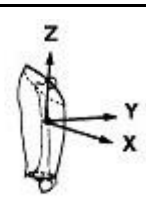
Axis	Min (kg·m2, (lb·ft2))	Max (kg·m2, (lb·ft2))
Xp	6.59 (156.38)	17.69 (419.79)
Yp	6.12 (145.23)	16.43 (389.89)
Zp	0.73 (17.32)	2.05 (48.65)

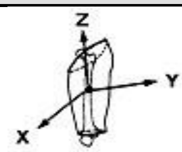
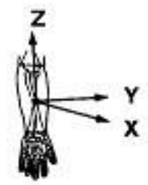
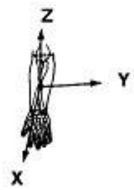
NOTE: The axes in the figure above represent the principal axes.

Table 50—Body-Segment Moment of Inertia of the Crewmember, Unsuited

Segment		Axis	Min (kg·m2x10-3 (lb·ft2x10- 3))	Max (kg·m2 x10-3 (lb·ft2x10- 3))
Head		Xp	15 (351)	22 (512)
		Yp	18 (424)	25 (587)
		Zp	14 (322)	16 (379)
Neck		Xp	0.7 (17)	2.2 (53)
		Yp	1.0 (23)	2.7 (64)
		Zp	1.1 (25)	3.4 (81)
Thorax		Xp	183 (4,346)	680 (16,134)
		Yp	135 (3,206)	505 (11,984)
		Zp	119 (2,833)	431 (10,236)
Abdomen		Xp	15 (347)	23 (540)
		Yp	10 (241)	13 (309)
		Zp	21 (500)	35 (826)
Pelvis		Xp	46 (1,092)	148 (3,514)
		Yp	34 (810)	137 (3,258)
		Zp	61 (1,440)	173 (4,104)
Torso		Xp	638 (15,143)	2,030 (48,178)
		Yp	577 (13,702)	1840 (43,654)
		Zp	205 (4,865)	644 (15,273)
Right upper arm		Xp	5.4 (129)	18 (430)
		Yp	5.6 (133)	19 (462)
		Zp	1.0 (24)	3.9 (92)
Left upper arm		Xp	5.3 (126)	17.7 (420)

Segment		Axis	Min (kg·m2x10-3 (lb·ft2x10- 3))	Max (kg·m2 x10-3 (lb·ft2x10- 3))
		Yp	5.5 (130)	19 (449)
		Zp	0.9 (22)	3.8 (89)
Right forearm		Xp	2.8 (67)	12 (276)
		Yp	2.7 (65)	12 (282)
		Zp	0.5 (11)	1.8 (43)
Left forearm		Xp	2.8 (66)	11 (257)
		Yp	2.7 (63)	11 (265)
		Zp	0.5 (11)	1.6 (39)
Right hand		Xp	0.6 (14)	1.6 (38)
		Yp	0.5 (11)	1.3 (31)
		Zp	0.2 (4)	0.5 (13)
Left hand		Xp	0.6 (15)	1.6 (37)
		Yp	0.5 (13)	1.3 (31)
		Zp	0.2 (4)	0.5 (12)
Right hip flap		Xp	8.1 (191)	17 (412)
		Yp	10 (246)	22 (530)
		Zp	13 (318)	29 (696)
Left hip flap		Xp	7.9 (188)	17 (398)
		Yp	11 (255)	22 (519)
		Zp	14 (324)	28 (671)
Right thigh minus flap		Xp	34 (800)	79 (1,885)
		Yp	33 (785)	82 (1,941)

Segment		Axis	Min (kg·m2x10-3 (lb·ft2x10- 3))	Max (kg·m2 x10-3 (lb·ft2x10- 3))
		Zp	14 (327)	32 (753)
Left thigh minus flap		Xp	34 (798)	75 (1,784)
		Yp	33 (789)	79 (1,878)
		Zp	13 (317)	31 (729)
Right calf		Xp	26 (615)	75 (1,790)
		Yp	26 (613)	76 (1,815)
		Zp	3.1 (73)	8.9 (210)
Left calf		Xp	26 (614)	77 (1,826)
		Yp	26 (615)	78 (1,855)
		Zp	3.0 (70)	9.1 (215)
Right foot		Xp	0.4 (9)	1.0 (24)
		Yp	1.6 (37)	5.5 (130)
		Zp	1.6 (39)	5.8 (138)
Left foot		Xp	0.4 (9)	1.0 (24)
		Yp	1.6 (39)	5.4 (127)
		Zp	1.7 (41)	5.7 (134)
Right thigh		Xp	85 (2,009)	208 (4,940)
		Yp	87 (2,063)	220 (5,215)
		Zp	27 (651)	59 (1,401)
Left thigh		Xp	85 (2,022)	200 (4,757)
		Yp	88 (2,088)	212 (5,024)

Segment		Axis	Min (kg·m2x10-3 (lb·ft2x10- 3))	Max (kg·m2 x10-3 (lb·ft2x10- 3))
		Zp	27 (649)	57 (1,350)
Right forearm plus hand		Xp	11 (262)	40 (939)
		Yp	11 (257)	39 (935)
		Zp	0.7 (16)	2.4 (58)
Left forearm plus hand		Xp	11 (260)	37 (887)
		Yp	11 (256)	37 (881)
		Zp	0.6 (15)	2.2 (53)

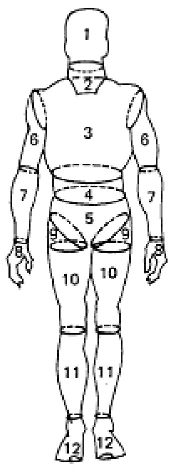
**The axes in the figures above represent the principal axes.*

F.6 BODY VOLUME

Table 51—Whole-Body Volume of Crewmember

Crewmember Body Volume (cm^3 [$in.^3$])	
Minimum	46,431 (2,833)
Maximum	113,556 (6,930)

Table 52—Body-Segment Volume of Crewmember



Segment	Volume (cm^3 [in.^{3}])	
	Minimum	**Maximum**
1 Head	3,692 (225)	4,607 (281)
2 Neck	575 (35)	1,455 (89)
3 Thorax	12,515(764)	36,034 (2,199)
4 Abdomen	1,104 (67)	3,562 (217)
5 Pelvis	4,961 (303)	17,469 (1,066)
6 Upper Arm*	957 (58)	2,901 (177)
7 Forearm*	643(39)	1,920(117)
8 Hand*	285 (17)	637 (39)
9 Hip Flap	2,510 (153)	5,191 (317)
10 Thigh minus Flap*	4,041 (247)	8,399 (513)
11 Calf*	2,195 (134)	5,062 (309)
12 Foot*	518 (32)	1,235 (75)
Torso (3 + 4 + 5)	19,269 (1,176)	57,498 (3,509)
Thigh (9 + 10)	6,571 (401)	13,424 (819)
Forearm plus Hand (7 + 8)*	930 (57)	2,556 (156)

**The minimum and maximum values for these segments were derived from the calculated average between the left and right segment values.*

F.7 CREWMEMBER STRENGTH

Strength refers to a person's ability to generate force. Applying the following strength requirements will result in a minimum and maximum applied crew load to be used for operational and hardware design. The minimum load pertains to operational strength that accommodates the weakest person while the maximum load represents the force the hardware must be able to withstand without failure. It is important to note that these requirements apply to intentional forces applied by the crewmember. Durability is applicable to structural integrity of hardware due to non-intentional crew forces which is handled through the structural design process defined in GP 10040, Gateway Loads Control Plan.

Tables F-6-1 through F-6-5 provide both minimum (operational) and maximum (withstand) strength capabilities for unsuited, suited unpressurized, and suited pressurized conditions.

F.7.1 Withstand (Maximum Strength) Crew Loads

Vehicle components and equipment are to be designed to withstand large forces exerted by a strong crewmember during nominal hardware operation, without breaking or sustaining damage that would deem the hardware inoperable. Humans may also exert high forces when operating controls in emergency situations, such as attempting to open a hatch for emergency egress. The resulting possible damage to equipment could make it impossible to respond safely to the emergency. To avoid overdesign, a task analysis is performed to identify which interfaces must tolerate maximum crew loads. This includes identifying critical hardware that may be inadvertently used as a mobility aid or restraint. Identified crew interfaces must withstand the value provided in the corresponding "withstand crew loads" column, which provides the maximum loads that crew can be expected to exert. The data provided in the tables are for unsuited, suited-unpressurized, and suited-pressurized conditions. Data was derived from a collection of journal articles associated with human strength data.

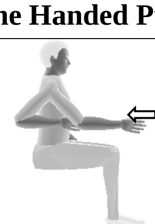
F.7.2 Crew Operational Loads (for Minimum Strength)

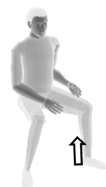
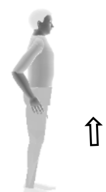
The design must allow for all crewmembers to perform any of the requested tasks efficiently and effectively, thus ensuring task and/or mission success. A human-centered design process is to be used when implementing operational strength limits. Analysis of expected crew operations, activities, and tasks is to drive the design of human-machine interfaces. The analysis should evaluate and define activities/tasks in terms of criticality and required postures. Identified crew interfaces must be actuated and operable at the value provided in the corresponding "Crew Operational Loads" columns, which provide the maximum load that the weakest crewmember could be expected to exert. The data provided in the tables are for unsuited, suited-unpressurized, and suited-pressurized conditions. Data was derived from a collection of journal articles associated with human strength data.

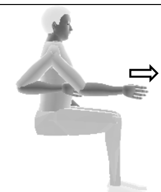
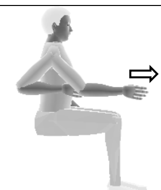
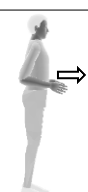
For this purpose, tasks that involve the possibility of a single failure causing loss of life or vehicle have a definition of Criticality 1 Operations in the following tables. Tasks involving Loss of Mission (LOM) alone have a definition of Criticality 2 Operations. The values in the criticality 1 and 2 columns also include decrement factor(s) to reflect the deconditioning effects on crewmembers after an extended duration of mission. All other tasks fall into the "Other Operations" category, and do not have deconditioning or a factor of safety applied over minimal anticipated crew strength. It is important to note that the designer should be careful not to implement multiple safety factors. For example, NASA-STD-5017 torque/force margin requirements (4.10.0) levy an extra safety factor on the applied torque/force to a given mechanism. Implementing this requirement along with the already built-in safety factor (i.e., criticality) in the strength tables results in an overly conservative design.

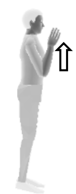
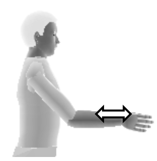
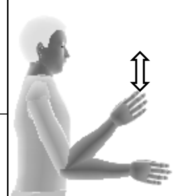
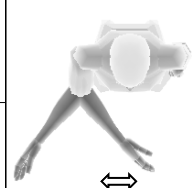
Data was derived from a collection of journal articles associated with human strength data. In addition, other references were used, such as the MIL-STD-1472F and the Occupational and Biomechanics textbook (Chaffin, D. B., Occupation Biomechanics, Second Edition, John Wiley & Sons, Inc., 1991), to set a standard for very specific strength data such as lifting strength

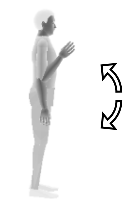
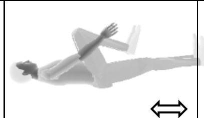
Table 53—Crew Loads, Unsuited

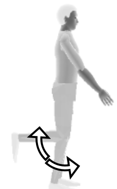
Type of Strength			Crew Operational Loads (N, (lbf))			Withstand Crew Loads (N, (lbf))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
One Handed Pulls						
Seated Horizontal Pull In[2]	Subject in a seated position pulls towards his/her body. Unilateral/Isometric measurement		111 (25)	147 (33)	276 (62)	449 (101)

Type of Strength			Crew Operational Loads (N, (lbf))			Withstand Crew Loads (N, (lbf))
			Crit 1 Ops	**Crit 2 Ops**	**Other Ops**	
Seated Vertical Pull Down[2]	Subject in a seated position pulls downwards. Unilateral/Isometric measurement		125 (28)	165 (37)	311 (70)	587 (132)
Seated Vertical Pull Up[2]	Sitting erect with feet apart, dominant hand grasping D-ring located directly to the front above the floor, pulling upward while keeping shoulder squares & other arm in lap		49 (11)	67 (15)	125 (28)	756 (170)
Standing Vertical Pull Up2	Standing erect with feet apart, dominant hand grasping underside of D-ring located directly to the side above standing surface, pulling upward while keeping shoulders square and other arm relaxed at side		53 (12)	71 (16)	133 (30)	725 (163)
Two Handed Pulls						
Standing Vertical Pull Down [2]	Standing erect with feet apart, with both hands holding handle located above shoulders, pulling downward		138 (31)	182 (41)	343 (77)	707 (159)
Standing Pull in[2]	Standing erect with feet apart, with both hands holding handle located in front, pulling inward towards body		58 (13)	80 (18)	147 (33)	391 (88)
Standing Vertical Pull Up[2]	Standing with feet apart with a slight bend at the knees and waist, grasping a handle with both hands located directly in front and pulling upward		89 (20)	116 (26)	218 (49)	1437 (323)
Seated Vertical Pull Up[2]	Sitting erect with feet apart, grasping both sides of handle located directly to the front above the floor, pulling upward using arms and shoulders		93 (21)	125 (28)	236 (53)	1188 (267)

Type of Strength			Crew Operational Loads (N, (lbf))			Withstand Crew Loads (N, (lbf))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
One Handed Push						
Seated Horizontal Push Out[2]	Subject in a seated position pushing away from his/her body. Unilateral/Isometric measurement		89 (20)	116 (26)	218 (49)	436 (98)
Seated Vertical Push Up[2]	Subject in a seated position pushing upward in a vertical direction. Unilateral/Isometric measurement		67 (15)	85 (19)	160 (36)	280 (63)
One Handed Push						
Seated Horizontal Push Out[2]	Subject in a seated position pushing away from his/her body. Unilateral/Isometric measurement		89 (20)	116 (26)	218 (49)	436 (98)
Seated Vertical Push Up[2]	Subject in a seated position pushing upward in a vertical direction. Unilateral/Isometric measurement		67 (15)	85 (19)	160 (36)	280 (63)
Two Handed Push						
Standing Vertical Push Down[2]	Standing with feet apart with a slight bend at the knees and waist, grasping a handle with both hands located directly in front and pushing downwards		102 (23)	133 (30)	254 (57)	525 (118)
Standing Horizontal Push Out1	Standing erect with feet apart, with both hands holding handle located in front, pushing out away from body		62 (14)	85 (19)	165 (37)	596 (134)

Type of Strength			Crew Operational Loads (N, (lbf))			Withstand Crew Loads (N, (lbf))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
Standing Vertical Push Up2	Standing erect with feet apart, grasping from below, both sides of handle located directly in front above standing surface. Pushing upwards using arms and shoulders		76 (17)	98 (22)	187 (42)	1094 (246)
Arms						
Arm Pull[2]	Subject pulls handle forward and backward		44 (10)	58 (13)	107 24)	249 (56)
Arm Push[2]	Subject pushes handle forward and backward		40 (9)	53 (12)	98 (22)	222 (50)
Arm Up[2]	Subject pushes and pulls handle in a various directions as shown by the figures		18 (4)	22 (5)	40 (9)	107 (24)
Arm Down[2]	Subject pushes and pulls handle in a various directions as shown by the figures		22 (5)	31 (7)	58 (13)	116 (26)
Arm In2	Subject moves handle medially		22 (5)	31 (7)	58 (13)	98 (22)
Arm Out2	Subject moves handle laterally		13 (3)	18 (4)	36 (8)	76 (17)
Lifting						
Lifting Strength[2]	Standing with feet apart with a slight bend at the knees and waist, grasping a handle with both hands located directly in front and pulling upward using primarily arms, shoulders, and legs		36 (8)	49 (11)	93 (21)	1228 (276)

Type of Strength			Crew Operational Loads (N, (lbf))			Withstand Crew Loads (N, (lbf))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
Elbow						
Flexion[2]	Subject moves forearm in a sagittal plane around the elbow joint		13 (3)	18 (4)	36 (8)	347 (78)
Extension[2]	Subject moves forearm in a sagittal plane around the elbow joint		27 (6)	36 (8)	67 (15)	249 (56)
Wrist & Hand						
Wrist Flexion[2]	Subject bends wrist in a palmar direction		31 (7)	40 (9)	76 (17)	209 (47)
Wrist Extension[2]	Subject bends the wrist in a dorsal direction		13 (3)	18 (4)	36 (8)	85 (19)
Pinch [1]	Subject squeezes together the thumb and finger		9 (2)	13 (3)	18 (4)	200 (45)
Grasp[1]	Subject maintains an eccentric tight hold of an object		347 (78)	463 (104)	694 (156)	1219 (274)
Grip[1]	Subject maintains a concentric tight hold of an object		49 (11)	67 (15)	102 (23)	783 (176)
Leg						
Hip Flexion[2]	Subject moves leg in the sagittal plane around the hip joint toward the front of the body		116 (26)	156 (35)	289 (65)	645 (145)
Hip Extension[2]	Subject moves upper and lower leg in a sagittal plane around the hip joint		191 (43)	254 (57)	476 (107)	658 (148)
Leg Press[1]	Subject moves leg in a sagittal plane around the hip joint toward the back of the body		618 (139)	827 (186)	1552 (349)	2584 (581)
Knee Flexion[1]	Subject moves lower leg in a sagittal plane around the knee joint		53 (12)	71 (16)	138 (31)	325 (73)

Type of Strength			Crew Operational Loads (N, (lbf)) Crit 1 Ops	Crit 2 Ops	Other Ops	Withstand Crew Loads (N, (lbf))
Knee Extension[1]	Subject moves lower leg in a sagittal plane around the knee joint		142 (32)	191 (43)	383 (86)	783 (176)

[1] Post space flight maximal measured strength decrement.
[2] Post space flight estimated strength decrement. Range is 0%-26%. Average estimated is 20%. Based on max EDOMP Data. Not all motions were measured on EDOMP.

Table 54—Torque Values for Pronation and Supination, Unsuited

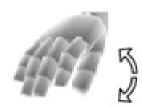
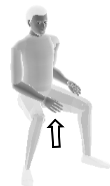
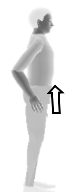
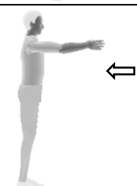
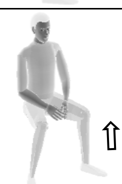
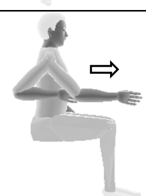
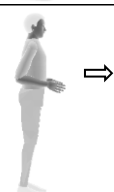
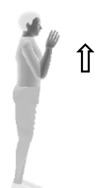
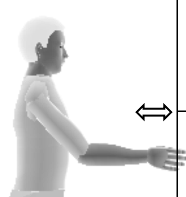
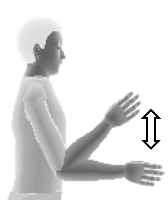
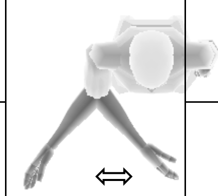
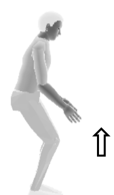
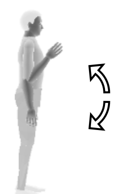
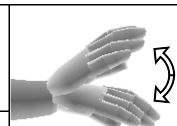
Type of Strength			Crew Operational Loads (N·m, (in·lb)) Crit 1 Ops	Crit 2 Ops	Other Ops	Withstand Crew Loads (N·m, (in·lb))
Pronation[2]	Subject rotates hands and forearms medially		0.8 (7.4)	1.1 (10)	2.1 (18.4)	11.3 (100)
Supination[2]	Subject rotates hands and forearms laterally		0.8 (7.4)	1.1 (10)	2.1 (8.4)	11.3 (100)

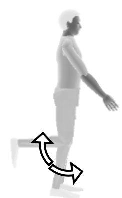
Table 55—Crew Loads, Unpressurized Suited

Type of Strength			Crew Operational Loads (N, (lbf)) Crit 1 Ops	Crit 2 Ops	Other Ops	Withstand Crew Loads (N, (lbf))
One Handed Pulls						
Seated Horizontal Pull In[2]	Subject in a seated position pulls towards his/her body. Unilateral/Isometric measurement		78 (18)	103 (23)	193 (43)	314 (71)
Seated Vertical Pull Down[2]	Subject in a seated position pulls downwards. Unilateral/Isometric measurement		88 (20)	116 (26)	218 (49)	411 (92)

Type of Strength			Crew Operational Loads (N, (lbf))			Withstand Crew Loads (N, (lbf))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
Seated Vertical Pull Up[2]	Sitting erect with feet apart, dominant hand grasping D-ring located directly to the front above the floor, pulling upward while keeping shoulder squares & other arm in lap		34 (8)	47 (11)	88 (20)	529 (119)
Standing Vertical Pull Up[2]	Standing erect with feet apart, dominant hand grasping underside of D-ring located directly to the side above standing surface, pulling upward while keeping shoulders square and other arm relaxed at side		37 (8)	50 (11)	93 (21)	508 (114)
Standing Vertical Pull Down[2]	Standing erect with feet apart, with both hands holding handle located above shoulders, pulling downward		97 (22)	127 (29)	240 (54)	495 (111)
Standing Pull in[2]	Standing erect with feet apart, with both hands holding handle located in front, pulling inward towards body		41 (9)	56 (13)	103 (23)	274 (62)
Standing Vertical Pull Up[2]	Standing with feet apart with a slight bend at the knees and waist, grasping a handle with both hands located directly in front and pulling upward		62 (14)	81 (18)	153 (34)	1006 (226)
Seated Vertical Pull Up[2]	Sitting erect with feet apart, grasping both sides of handle located directly to the front above the floor, pulling upward using arms and shoulders		65 (15)	88 (20)	165 (37)	832 (187)
Seated Horizontal Push Out[2]	Subject in a seated position pushing away from his/her body. Unilateral/Isometric measurement		62 (14)	81 (18)	153 (34)	305 (69)

Type of Strength			Crew Operational Loads (N, (lbf))			Withstand Crew Loads (N, (lbf))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
Seated Vertical Push Up[2]	Subject in a seated position pushing upward in a vertical direction. Unilateral/Isometric measurement		47 (11)	60 (13)	112 (25)	196 (44)
Two Handed Push						
Standing Vertical Push Down[2]	Standing with feet apart with a slight bend at the knees and waist, grasping a handle with both hands located directly in front and pushing downwards		71 (16)	93 (21)	178 (40)	368 (83)
Standing Horizontal Push Out[1]	Standing erect with feet apart, with both hands holding handle located in front, pushing out away from body		43 (10)	60 (13)	116 (26)	417 (94)
Standing Vertical Push Up[2]	Standing erect with feet apart, grasping from below, both sides of handle located directly in front above standing surface. Pushing upwards using arms and shoulders		53 (12)	69 (15)	131 (29)	766 (172)
Arms						
Arm Pull[2]	Subject pulls handle forward and backward		31 (7)	41 (9)	75 (17)	174 (39)
Arm Push[2]	Subject pushes handle forward and backward		28 (6)	37 (8)	69 (15)	155 (35)
Arm Up[2]	Subject moves handle up		13 (3)	15 (4)	28 (6)	75 (17)
Arm Down[2]	Subject moves handle down		15 (4)	22 (5)	41 (9)	81 (18)

Type of Strength			Crew Operational Loads (N, (lbf))			Withstand Crew Loads (N, (lbf))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
Arm In[2]	Subject moves handle medially		15 (4)	22 (5)	41 (9)	69 (15)
Arm Out[2]	Subject moves handle laterally		9 (2)	13 (3)	25 (6)	53 (12)
Lifting						
Lifting Strength[2]	Standing with feet apart with a slight bend at the knees and waist, grasping a handle with both hands located directly in front and pulling upward using primarily arms and shoulders, and legs		25 (6)	34 (8)	65 (15)	860 (193)
Elbow						
Flexion[2,3]	Subject moves forearm in a sagittal plane around the elbow joint		9 (2)	13 (3)	25 (6)	243 (55)
Extension[2,3]	Subject moves forearm in a sagittal plane around the elbow joint		19 (4)	25 (6)	47 (11)	174 (39)
Wrist & Hand						
Wrist Flexion[2,3]	Subject bends wrist in a palmar direction		22 (5)	28 (6)	53 (12)	146 (33)
Wrist Extension[2,3]	Subject bends the wrist in a dorsal direction		9 (2)	13 (3)	25 (6)	60 (13)
Pinch [1]	Subject squeezes together the thumb and finger		14 (3)	20 (5)	27 (6)	300 (68)
Grasp[1,3]	Subject maintains an eccentric tight hold of an object		243 (55)	324 (73)	486 (109)	853 (192)
Grip[1]	Subject maintains a concentric tight hold of an object		25 (6)	34 (8)	51 (12)	392 (88)

Type of Strength			Crew Operational Loads (N, (lbf))			Withstand Crew Loads (N, (lbf))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
Legs						
Hip Flexion[2,3]	Subject moves leg in the sagittal plane around the hip joint toward the front of the body		81 (18)	109 (25)	202 (46)	452 (102)
Knee Flexion[1,3]	Subject moves lower leg in a sagittal plane around the knee joint, decreasing the angle between the upper and lower leg		37 (8)	50 (11)	97 (22)	228 (51)
Knee Extension[1,3]	Subject moves lower leg in a sagittal plane around the knee joint, increasing the angle between the upper and lower leg		99 (22)	134 (30)	268 (60)	548 (123)

1. Post space flight maximal measured strength decrement.
2. Post space flight estimated strength decrement. Range is 0%-47%. Average estimated is 33%. Based on CRV Requirements Document.
3. Suit decrement not measured directly, but estimated based on functional strength testing of other movements

Table 56—Torque Values Pronation and Supination, Unpressurized Suited

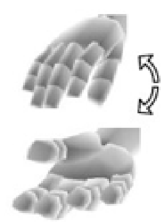
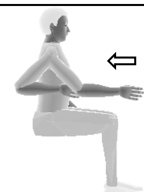
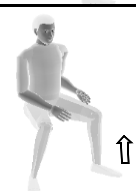
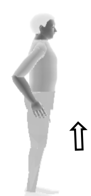
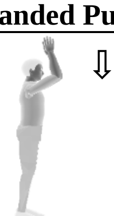
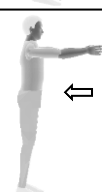
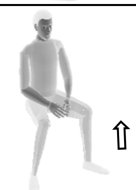
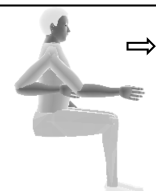
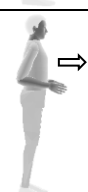
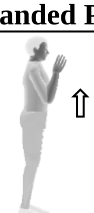
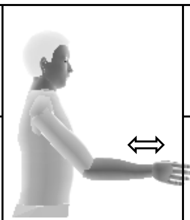
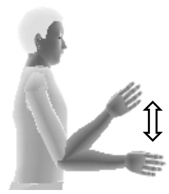
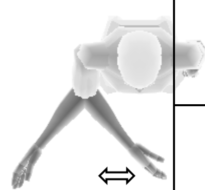
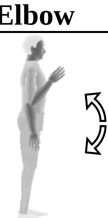
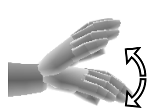
Type of Strength			Crew Operational Loads (N·m, (in·lb))			Withstand Crew Loads (N·m, (in·lb))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
Pronation[2]	Subject rotates hands and forearms medially		0.7 (6.4)	0.9 (8.5)	1.8 (16)	13.1 (116)
Supination[2]	Subject rotates hands and forearms laterally		0.7 (6.4)	0.9 (8.5)	1.8 (16)	13.1 (116)

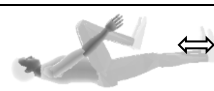
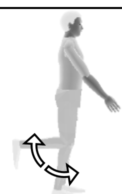
Table 57—Crew Loads, Pressurized Suited

(Only for an EVA type suit and not for a launch and entry type suit, due to extreme difficulty of the LEA suit to operate under pressurized condition)

Type of Strength			Crew Operational Loads (N(lbf))			Withstand Crew Loads (N(lbf))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
One Handed Pulls						
Seated Horizontal Pull In[2]	Subject in a seated position pulls towards his/her body. Unilateral/ Isometric measurement		56 (13)	74 (17)	138 (31)	225 (51)
Seated Vertical Pull Down[2]	Subject in a seated position pulls downwards. Unilateral/Isometric measurement		63 (14)	83 (19)	156 (35)	294 (66)
Seated Vertical Pull Up[2]	Sitting erect with feet apart, dominant hand grasping D-ring located directly to the front above the floor, pulling upward while keeping shoulder squares & other arm in lap		25 (6)	34 (8)	63 (14)	378 (85)
Standing Vertical Pull Up[2]	Standing erect with feet apart, dominant hand grasping underside of D-ring located directly to the side above standing surface, pulling upward while keeping shoulders square and other arm relaxed at side		27 (6)	36 (8)	67 (15)	363 (82)
Two Handed Pulls						
Standing Vertical Pull Down [2]	Standing erect with feet apart, with both hands holding handle located above shoulders, pulling downward		69 (16)	91 (21)	172 (39)	354 (80)
Standing Pull In[2]	Standing erect with feet apart, with both hands holding handle located in front, pulling inward towards body		29 (7)	40 (9)	74 (17)	196 (44)

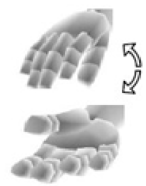
Type of Strength			Crew Operational Loads (N(lbf))			Withstand Crew Loads (N(lbf))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
Standing Vertical Pull Up[2]	Standing with feet apart with a slight bend at the knees and waist, grasping a handle with both hands located directly in front and pulling upward		45 (10)	58 (13)	109 (25)	719 (162)
Seated Vertical Pull Up[2]	Sitting erect with feet apart, grasping both sides of handle located directly to the front above the floor, pulling upward using arms and shoulders		47 (11)	63 (14)	118 (27)	594 (134)
One Handed Push						
Seated Horizontal Push Out[2]	Subject in a seated position pushing away from his/her body. Unilateral/Isometric measurement		45 (10)	58 (13)	109 (25)	218 (49)
Seated Vertical Push Up[2]	Subject in a seated position pushing upward in a vertical direction. Unilateral/Isometric measurement		34 (8)	43 (10)	80 (18)	140 (32)
Two Handed Push						
Standing Vertical Push Down[2]	Standing with feet apart with a slight bend at the knees and waist, grasping a handle with both hands located directly in front and pushing downwards		51 (12)	67 (15)	127 (29)	263 (59)
Standing Horizontal Push Out[1]	Standing erect with feet apart, with both hands holding handle located in front, pushing out away from body		31 (7)	43 (10)	83 (19)	298 (67)
Two Handed Push						
Standing Vertical Push Up[2]	Standing erect with feet apart, grasping from below, both sides of handle located directly in front above standing surface. Pushing upwards using arms and shoulders		38 (9)	49 (11)	94 (21)	547 (123)

Type of Strength			Crew Operational Loads (N(lbf))			Withstand Crew Loads (N(lbf))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
Arm						
Arm Pull[2]	Subject pulls handle forward and backward		22 (5)	29 (7)	54 (12)	125 (28)
Arm Push[2]	Subject pushes handle forward and backward		20 (5)	27 (6)	49 (11)	111 (25)
Arm Up[2]	Subject moves handle up		9 (2)	11 (3)	20 (5)	54 (12)
Arm Down[2]	Subject moves handle down		11 (3)	16 (4)	29 (7)	58 (13)
Arm In[2]	Subject moves handle medially		11 (3)	16 (4)	29 (7)	49 (11)
Arm Out[2]	Subject moves handle laterally		7 (2)	9 (2)	18 (4)	38 (9)
Lifting						
Lifting Strength[2]	Standing with feet apart with a slight bend at the knees and waist, grasping a handle with both hands located directly in front and pulling upward using primarily arms and shoulders, and legs		18 (4)	25 (6)	47 (11)	614 (138)
Elbow						
Flexion[2, 3]	Subject moves forearm in a sagittal plane around the elbow joint		7 (2)	9 (2)	18 (4)	174 (39)
Extension[2, 3]	Subject moves forearm in a sagittal plane around the elbow joint		14 (3)	18 (4)	34 (8)	125 (28)
Wrist & Hand						
Wrist Flexion[2, 3]	Subject bends wrist in a palmar direction		19 (4)	25 (6)	37 (8)	101 (23)
Wrist Extension[2,3]	Subject bends the wrist in a dorsal direction		7 (2)	9 (2)	14 (3)	33 (7)

Type of Strength			Crew Operational Loads (N(lbf))			Withstand Crew Loads (N(lbf))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
Pinch [1]	Subject squeezes together the thumb and finger		14 (3)	20 (5)	27 (6)	300 (68)
Grasp[1,3]	Subject maintains an eccentric tight hold of an object		174 (39)	232 (52)	347 (78)	610 (137)
Grip[1]	Subject maintains a concentric tight hold of an object		25 (6)	34 (8)	51 (12)	392 (88)
Leg						
Hip Flexion[2,3]	Subject moves leg in the sagittal plane around the hip joint toward the front of the body		58 (13)	78 (18)	145 (33)	323 (73)
Hip Extension[2,3]	Subject moves leg in a sagittal plane around the hip joint toward the back of the body		96 (22)	127 (29)	238 (54)	329 (74)
Leg Press[1,3]	Subject pushes a weight away from them using their legs		309 (70)	414 (93)	776 (175)	1292 (291)
Knee Flexion[1,3]	Subject moves lower leg in a sagittal plane around the knee joint		27 (6)	36 (8)	69 (16)	163 (37)
Knee Extension[1]	Subject moves lower leg in a sagittal plane around the knee joint		71 (16)	96 (22)	192 (43)	392 (88)

1. Post space flight maximal measured strength decrement.
2. Post space flight estimated strength decrement. Range is 0%-47%. Average estimated is 33%. Based on CRV Requirements Document.
3. Suit decrement not measured directly, but estimated based on functional strength testing of other movements

Table 58—Torque Values Pronation and Supination, Pressurized Suited

Type of Strength			Crew Operational Loads (N·m, (in·lb))			Withstand Crew Loads (N·m, (in·lb))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
Pronation[2]	Subject rotates hands and forearms medially		0.9 (8)	1.2 (11)	2.3 (20)	13 (115)
Supination[2]	Subject rotates hands and forearms laterally		0.9 (8)	1.2 (11)	2.3 (20)	13 (115)