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1 Introduction

On March 26, 2019, Vice President Michael R. Pence on behalf of the President directed NASA to return American astronauts to the lunar surface within the next five years, a dramatic acceleration of the agency's human space exploration plans. In support of this goal, the United States will:

a. Implement a sustained human and robotic program to explore the lunar surface and beyond.
b. Extend human presence across the solar system, starting with a human return to the Moon by the year 2024, in preparation for human exploration of Mars and other destinations.
c. Develop the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about future destinations for human exploration.
d. Promote commercial participation in exploration to further U.S. scientific, security, and economic interests.

The requirements defined within section 4 of this document were derived from the HLS objectives documented in section 3.

1.1 Scope and Purpose

This document establishes the performance objectives and design requirements for the Human Landing System (HLS). In section 3, NASA has established an HLS Statement of Objectives (SOO) that sets forth the top-level outcomes and objectives for HLS that Offerors must achieve. Derived from these overarching objectives, the HLS Program has established a minimal set of 26 HLS performance requirements identifying the functionality of the integrated lander system in the initial and sustained configurations excluding the launch vehicle(s). These requirements, contained in section 4, address the "what" to build. Offerors shall develop unique, innovative, and cost-effective solutions that achieve NASA's overarching objectives while meeting (or exceeding) these defined functional and performance requirements. For some of these 26 requirements, the Government has provided thresholds (minimum requirements) as well as goals; the Contractor shall meet or exceed the thresholds, and may be evaluated more favorably if it meets or exceed the specified goals.

Appendix A contains NASA's current understanding of the HLS interfaces that the providers should address within their proposal. The HLS integrated lander must successfully interface with these systems. The Offeror's proposal must:

(1) Utilize these interface definitions as defined in Appendix A **or**

(2) Propose interfaces that fully meet the intent defined in Appendix A

Appendices B through D contain NASA standards that set forth a potential approach for how NASA would design, build, certify, and operate an HLS. These appendices are

offered in this document as a starting point for the Offeror's proposal for all work to be performed through the end of the contract. The Offeror's proposal shall:

(1) Demonstrate that the proposal meets or exceeds each NASA standard

(2) Employ an alternative approach to a specific standard which the Offeror asserts is equivalent in outcome, with a thorough explanation of such equivalency and a rationale in support of this approach in lieu of NASA's specification (i.e., a "meets the intent of" approach); and/or

(3) On a case-by-case basis, provide an approach that does not meet a particular NASA standard or its intent, but results in a demonstrably better approach that is more likely to enable the Offeror's ability to achieve one or more of NASA's overarching objectives and functional performance requirements as set forth in section 3 and 4 of this document.

While the Offeror's Performance Work Statement and technical design proposal will be incorporated into the contract at time of award if awarded a Base CLIN, NASA will work with each HLS Contractor during the contract's base period to arrive at a unique, final set of agreed-to HLS specifications and standards that each Contractor will be required to meet if the Contractor is awarded an Option A CLIN. In addition, if these revisions to specifications support an increase or decrease to the Offeror's originally-proposed firm fixed price for the Option A CLIN, NASA will permit the Contractor to submit an updated firm fixed price for Option A to accommodate and account for these revisions before NASA evaluates whether to award Option A to the Contractor. If the Contractor and NASA cannot reach agreement on the use of a proposed alternate standard or approach, the Contractor will be required to apply the applicable NASA standard for purposes of finalizing the Contractor's final technical proposal for Option A.

For the first demonstration mission(s) beginning in 2024, the Contractor shall deliver a system that can dock to either Gateway or Orion. For the sustained mission(s) starting in 2026, the Contractor shall deliver a system that can dock to Gateway. Gateway has established a passive interface mechanism for docking. Orion has established an active interface mechanism for docking. If the Contractor uses a docking adapter to interface between HLS and Gateway, and leaves the docking adapter at Gateway during the mission, the Government will take title to the Contractor's provided docking adapter

1.2 Convention and Notification

"Initial" Requirements – Requirements indicated by the designation "initial," are those that are levied on the first demonstration mission(s), beginning in 2024 (Artemis 3).

"Sustained" Requirements – Requirements indicated by the designation "sustained," apply to the demonstration of the HLS *sustainable* capabilities (2026) after the demonstration of HLS initial capabilities (2024).

Note: **Requirements that are not "initial" or "sustained," are assumed to be applicable to every configuration.**

"Rationale" statements are intended to provide clarification, justification, purpose, and/or the source of a requirement. In the event that there is an inconsistency between a requirement and its rationale, the requirement always take precedence.

1.3 Measurement Units

Numerical data entered in shall be in International System of Units (SI) (metric) units with applicable tolerances. When appropriate the equivalent value in English Units should be added in parenthesis. Conversions between English and SI units shall be in accordance with ASTM E–380, standard procedure for use of the SI.

1.4 Human Rating Certification

This SRD (HLS-RQMT-001) also provides data for Human Rating certification that NASA would expect to be addressed in the potential provider's proposal (Appendix C). Offerors shall develop unique, innovative, and cost-effective HLS solutions that achieve NASA's overarching objectives while meeting its required performance objectives. This data flows from the HEOMD-003, "*Crewed Deep Space Systems Certification Requirements and Standards for NASA Missions*," which defines the requirements, standards and Human Rating Certification Package (HRCP) contents that will be used to certify crewed deep space systems, and achieve Human Rating compliance**.** The Human Rating requirements prescribe that a human-rated system accommodates human needs, effectively utilizes human capabilities, controls hazards with sufficient certainty to be considered safe for human operations, and provides, to the maximum extent practical, the capability for the crew and vehicle to safely recover from hazardous situations.

Formal Human Rating certification will be obtained by the HLS program for each mission prior to each HLS crewed phase. The HLS vendors will be expected to provide the data as specified in their contract to support the human-rating compliance assessment.

2 Documents

For the purpose of this document, the term 'document' can also refer to 'digital artifacts,' 'models,' or 'viewpoints' as needed to convey and exchange configuration managed data or information. An objective of the HLS Program is to advance towards a digital engineering environment and away from the traditional document-based approach for capturing data, reports and baselines.

2.1 Standards

The following documents may include specifications, models, standards, guidelines, handbooks, and other special publications that are called out in this document. These documents should be used as a basis for potential providers to build a proposal that will result in a human certifiable system. During the initial base period potential providers will work collaboratively with NASA to further refine their proposals based on these documents.

Appendices B through D contain NASA standards that set forth a potential approach for how NASA would design, build, certify, and operate an HLS. These appendices are offered in this document as a starting point for the Offeror's proposal for all work to be performed through the end of the contract. The Offeror's proposal shall:

(1) Demonstrate that the proposal meets or exceeds each NASA standard

(2) Employ an alternative approach to a specific standard which the Offeror asserts is equivalent in outcome, with a thorough explanation of such equivalency and a rationale in support of this approach in lieu of NASA's specification (i.e., a "meets the intent of" approach); and/or

(3) On a case-by-case basis, provide an approach that does not meet a particular NASA standard or its intent, but results in a demonstrably better approach that is more likely to enable the Offeror's ability to achieve one or more of NASA's overarching objectives and functional performance requirements as set forth in section 3 and 4 of this document.

While the Offeror's Performance Work Statement and technical design proposal will be incorporated into the contract at time of award if awarded a Base CLIN, NASA will work with each HLS Contractor during the contract's base period to arrive at a unique, final set of agreed-to HLS specifications and standards that each Contractor will be required to meet if the Contractor is awarded an Option A CLIN. In addition, if these revisions to specifications support an increase or decrease to the Offeror's originally-proposed firm fixed price for the Option A CLIN, NASA will permit the Contractor to submit an updated firm fixed price for Option A to accommodate and account for these revisions before NASA evaluates whether to award Option A to the Contractor. If the Contractor and NASA cannot reach agreement on the use of a proposed alternate standard or approach, the Contractor will be required to apply the applicable NASA standard for purposes of finalizing the Contractor's final technical proposal for Option A.

The following tables within this section are a listing of documents and standards sited within Appendix B thought D with corresponding sections within those documents that should be considered pertinent and relevant to HLS.

Table 1: Health and Medical TA Documents

Document Number	Document Name	Relevance
NASA-STD-3001 Volume 2 Rev B	NASA Space Flight Human-System Standard Volume 2: Human Factors, Habitability, and Environmental Health	Fully Relevant
NASA-STD-3301 Volume 1 Rev A	NASA Space Flight Human-System Standard Volume 1: Crew Health	Fully Relevant
See Appendix H Solicitation Attachments	Physical Capabilities and Characteristics	Fully Relevant

Table 2: Engineering TA Documents

Document Number	Document name	Relevance
NASA-STD-7009	Program Modeling and Simulation	Fully Relevant
IPC J-STD-001FS	Requirements for Soldered Electrical and Electronic Assemblies	Fully Relevant (For Relevance: also a child in SMA standard NASA-STD-8739.4A)
IPC J-STD-001F/ Amendment 1	Space Applications Electronic Hardware Addendum to J-STD 001E, Requirements for Soldered Electrical and Electronic Assemblies	Reference (For Relevant: also a child in SMA standard NASA-STD-8739.4A)
HLS-STD-007	Human Lander System Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment Document	Fully Relevant
NASA-STD-4003	Electrical Bonding For NASA Launch Vehicles, Spacecraft, Payloads, And Flight Equipment	Fully Relevant
ANSI/ESD S20.20	For the Development of an	Fully Relevant

Document Number	Document name	Relevance
	Electrostatic Discharge Control Program for - Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices)	(For Relevant: also a child in SMA standard NPD 8730.5B)
IPC-2220 series per Performance Class 3.	Family of Printed Board Design Documents	Fully Relevant per Performance Class 3.
	2221: B	
	2222: A	
	2223: D	
	2224: BL	
	2225: BL	
	2226: BL	
IPC-6010 Series	Family of Printed Board Performance Documents	Fully Relevant
	6011: BL	
	6012: DS	
	6013: C	
	6015: BL	
	6017: BL	
	6018: CS	
MIL-STD-464	Electromagnetic Environmental Effects (E3) Requirements for Systems	Fully Relevant
MIL-STD-981	Design, Manufacturing and Quality Standards for Custom Electromagnetic Devices for Space Applications	Fully Relevant

Document Number	Document name	Relevance
SMC-S-010	Space and Missile Systems Center Standard, Parts, Materials, and Processes Technical Requirements for Space and Launch Vehicles	Relevant for the EEE Parts Sections. Below are the sections of SMC-S-010 that are NOT applicable for EEE parts.
		1. Paragraphs 4.1.2, 4.3.1.2, 4.3.2
		2. Paragraphs 4.5 and 4.7 including their sub paragraphs
		3. Sections 100, 110, 120 and 1700 through 3500 inclusive.
		4. Appendix D
		All other parts of the document are relevant.
JSC 20793	Crewed Space Vehicle Battery Safety Requirements	Fully Relevant
AIAA S-111-2005	Qualification and Quality Requirements for Space Solar Cells	Fully Relevant
AIAA-S-112-2005	Qualification and Quality Requirements for Space Solar Panels	Fully Relevant
JSC 62809	Human Rated Spacecraft Pyrotechnic Specification	Fully Relevant
NPR 7150.2C	NASA Software Engineering Requirements	Fully Relevant
JSC 65829	Loads and Structural Dynamics Requirements for Spaceflight Hardware	Fully Relevant

Document Number	Document name	Relevance
JSC 67035	Best Practices and Guidelines (BP&G) for Thin Wall Pressure Boundaries (TWPB) for Human Spaceflight Applications	Fully Relevant
NASA-STD-5017	Design and Development Requirements for Mechanisms	Fully Relevant
NASA-STD-5018	Strength Design and Verification Criteria for Glass, Ceramics, and Windows in Human Spaceflight Applications	Fully Relevant
NASA-STD-5020	Requirements for Threaded Fastening Systems in Spaceflight Hardware	Fully Relevant
NASA-STD-6016	Standard Materials and Processes Requirements for Spacecraft	Relevant (For Relevant: also a child in SMA standard NASA-STD-8739.4A)
SMC Standard SMC-S-016 (2018)	Test Requirements for Launch, Upper-Stage, and Space Vehicles	Fully Relevant
JSC 65828	Structural Design Requirements and Factors of Safety for Spaceflight Hardware	Fully Relevant
NASA-STD-5019	Fracture Control Requirements for Spaceflight Hardware, for hardware structures of the integrated vehicle	Fully Relevant
AIAA-S-080-2018	Metallic Pressure Vessels, Pressurized Structures and Pressurized Components	Relevant (For Relevant: also a child in SMA standard NPD 8710.5D)
MSFC-DWG-20M02540	Assessment of Flexible Lines for Flow Induced Vibrations	Relevant
AIAA-S-081-2018	Composite Overwrapped	Relevant

Document Number	Document name	Relevance
	Pressure Vessels	(For Relevant: also a child in SMA standard NPD 8710.5D)
NASA-STD-5012	Strength and Life Assessment Requirements For Liquid-Fueled Space Propulsion System Engine	Fully Relevant

Table 3: SMA TA Documents

Document Number	Document name	Relevance
NPD 8730.2C	NASA Parts Policy	Relevant Chapters 1, 5.e, and 5.f.1 - .5.f.4, 5.f.5** - 5.f.6, Attachment B, and Attachment C.
NPR 8715.3D	NASA General Safety Program Requirements	Relevant Sections 1.7.4.2.a, 1.7.4.2.f-h, 3.15.7 - 3.15.8 (in-flight lasers and laser operations), 6** (if radioactive material is to be flown)Relevant

Document Number	Document name	Relevance
NASA-STD-8719.13C	Software Safety Standard	Relevant Chapters 4-7, Appendix A Note that Appendix A designates how to assess the safety criticality of software, as referred to in various other documents (e.g., NPR 7150.2, NASA Software Engineering Requirements)
NASA-STD-8739.1B	Workmanship Standard for Workmanship Standard for Polymeric Application on Electronic Assemblies	Fully Relevant.
NASA-STD-8739.4A	Workmanship Standard for Crimping, Interconnecting Cables, Harnesses, and Wiring	Relevant. Note: Per NPD 8730.5B, Appendix A, compliance is required with either this standard or IPC®/WHMA-A-620B and its space addendum IPC®/WHMA-A-620B-S
NASA-STD-8739.5A	Workmanship Standard For Fiber Optic Terminations, Cable Assemblies, and Installation	Fully Relevant.
NASA-STD-8739.6A	Implementation Requirements for NASA Workmanship Standards	Fully Relevant.
NASA-STD-8739.10	Electrical, Electronic, And Electromechanical (EEE) Parts Assurance Standard	Relevant sections 4-8

2.2 Reference Documents

The following documents contain supplemental information to guide the user in the application of this document. These may be called out in section 4 rationale or other areas of the document.

Table 4: Interoperability Documents

Document Number	Document Name	Applicability Comments
International Avionics System Interoperability Standards (IASIS)	HEOMD-003 V1	Reference.

Document Number	Document Name	Applicability Comments
International Communication System Interoperability Standards (ICSIS)	HEOMD-003 V2	Reference.
International Environmental Control and Life Support Systems (ECLSS) Interoperability Standards (IECLSSIS)	HEOMD-003 V3	Reference.
International Space Power System Interoperability Standards (ISPSIS)	HEOMD-003 V4	Reference.
International Rendezvous System Interoperability Standards (IRSIS)	HEOMD-003 V5	Reference.
International External Robotic Interoperability Standards (IERIS)	HEOMD-003 V6	Reference.
International Thermal System Interoperability Standards (ITIS)	HEOMD-003 V7	Reference.
International Software System Interoperability Standards (ISwSIS)	HEOMD-003 V8	Reference.

Table 5: Reference Health and Medical TA Documents

Document Number	Document Name	Applicability
NASA/SP-2010-3407[1]	Human Integration Design Handbook	Reference
NASA/TP-2014-218556	Human Integration Design Processes	Reference
NPD 8900.5 B	NASA Health and Medical Policy for Human Space Exploration	Reference

Document Number	Document Name	Applicability
ACGIH TLVs® and BEIs®, 2014 (or later)	American Conference of Governmental Industrial Hygienists (ACGIH) standard for "Threshold Limit Values (TLVs®) and Biological Exposure Indices (BEIs®)," sections Infrasound and Low-Frequency Sound, Light and Near-Infrared Radiation, and Ultraviolet Radiation	Reference
MIL-STD-1474 E	Department of Defense Design Criteria Standard, Noise Limits	Reference
NASA/SP-2015-3709	Human Systems Integration (HSI) Practitioner's Guide	Reference
SA-16-156	Level II JSC CMO HMTA Position on NHV and Internal Layout Considerations for Exploration Missions	Reference
NASA/TP-2014-218556	Human Interface Design Process	Reference
NASA/TM-2015-218564	Minimum Acceptable Net Habitable Volume for Long-Duration Exploration Missions	Reference
JSC 63414	Spacecraft Water Exposure Guidelines (SWEG)	Reference
JSC 20584	Spacecraft Maximum Allowable Concentrations (SMAC) for Airborne Contaminants	Reference

Document Number	Document Name	Applicability
JSC 26895	Guidelines for Assessing the Toxic Hazard of Spacecraft Chemicals and Test Materials	Reference
ANSI S12 65-2006	American National Standard for Rating Noise with Respect to Speech Interference	Reference
JSC 22538	Flight Crew Health Stabilization Program	Reference
JSC-28379	Medical Effects Of Iodine: Proceedings Of NASA/JSC Conference" March 1998.	Reference
JSC 63555	Nutrition requirements, Standards, and Operating Bands for Exploration Missions	Reference
JPR-1800.5	Biosafety Review Board Operations and Requirements	Reference
ITU P.863	Perceptual Objective Listening Quality Assessment	Reference
<TBS-SRD-001>	Display Standards for Human Landing System (HLS)	Reference
ISO 20283-5:2016(E),	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	Reference
TOX-VER-2016-03	Combustion Product Memo	Reference

Document Number	Document Name	Applicability
NASA/TM- 2013-217380REV1	Application of the Brinkley Dynamic Response Criterion to Spacecraft Transient Dynamic Events	Reference
Electronic Code of Federal Regulations, 1915.12(a)(2), March 28, 2017)	Precautions and the order of testing before entering confined and enclosed spaces and other dangerous atmospheres.	Reference
(Chapter 6 of): 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);	Oxygen Toxicity (Clark, J.M.)	Reference
ISO 2631-1:1997(E),	MECHANICAL VIBRATION AND SHOCK -- EVALUATION OF HUMAN EXPOSURE TO WHOLE-BODY VIBRATION -- PART 1: GENERAL REQUIREMENTS	Reference
ISO-9241-11	ERGONOMICS OF HUMAN-SYSTEM INTERACTION -- PART 11: USABILITY: DEFINITIONS AND CONCEPTS	Reference
ISO 7731:2003(E),	ERGONOMICS -- DANGER SIGNALS FOR PUBLIC AND WORK AREAS -- AUDITORY DANGER SIGNALS	Reference
ISO 3382:1997	ACOUSTICS -- MEASUREMENT OF THE REVERBERATION TIME OF ROOMS WITH REFERENCE TO OTHER ACOUSTICAL PARAMETERS	Reference
ANSI/ASA S3.2-2009	Method For Measuring The Intelligibility Of Speech Over Communication Systems	Reference

Document Number	Document Name	Applicability
ANSI C78.377	Electric Lamps — Specifications for the Chromaticity of Solid-State Lighting Products	Reference
ANSI Z136.1, 2014	“American National Standard for Safe Use of Lasers”, Table 5 (ocular) and Table 7 (dermal) without personal protective equipment.	Reference
IEC 60479-1	Effects of current on human beings and livestock - Part 1: General aspects	Reference
IEC 60479-1, Table 1	Effects of current on human beings and livestock - Part 1: General aspects	Reference
IEC 60479-2	Effects of current on human beings and livestock - Part 2: Special aspects	Reference
IEC 60479-5	Effects of current on human beings and livestock - Part 5: Touch voltage threshold values for physiological effects	Reference
NASA-TN-D-5153	The use of pilot rating in the evaluation of aircraft handling qualities	Reference
NASA/TP-1998-207978	Elements of Spacecraft Cabin Air Quality Design	Reference
JSC 39116	EMU Phase VI Glove Thermal Vacuum Test and Analysis Final Report; Bue, 2009	Reference
JSC-66320	Optical Property Requirements for Glasses, Ceramics, and Plastics in Spacecraft Window Systems	Reference
IEEE C95.1-2005	IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency	Reference

Document Number	Document Name	Applicability
	Electromagnetic Fields, 3 kHz to 300 GHz	
ACGIH 2014	Guide to Occupational Exposure Values	Reference
IES TM-30	Method for Evaluating Light Source Color Rendition	Reference
DOI: 10.1007/978-1-4939-1732-7_26	Normalization and Scaling for Human Response Corridors and Development of Injury Risk Curves (chapter from Accidental Injury: Biomechanics and Prevention, N. Yoganadan, A. Nahum and J. Melvin. New York, Springer Science+Business Media: 769-792.)	Reference
NASA/TP-2015-218578	Final NASA Panel Recommendations for Definition of Acceptable Risk of Injury due to Spaceflight Dynamic Events	Reference

Table 6: Reference Engineering TA Documents

Document Number	Document Name	Applicability Comments
DSG-PLAN-016	Gateway Program Modeling and Simulation Plan	Reference
MIL-STD-461	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment	Reference
DSG-RQMT-004	Gateway Electromagnetic Environmental Effects (E3) Requirements Document	Reference

EEE-INST-002	Instructions for EEE Parts Selection, Screening, Qualification, and Derating	Reference
DSG-RQMT-006	Gateway Loads and Structural Dynamics Requirements for Spaceflight Hardware	Reference
DSG-RQMT-008	Gateway Design and Development Requirements for Mechanisms	Reference
DSG-RQMT-009	Gateway Requirements for Threaded Fastening Systems in Spaceflight Hardware	Reference
DSG-RQMT-005	Gateway Structural Design Requirements and Factors of Safety for Spaceflight Hardware	Reference
DSG-RQMT-019	Gateway Fracture Control Requirements for Spaceflight Hardware	Reference

Table 7: Reference SMA TA Documents

Document Number	Document Name	Applicability Comments
NPD 8710.5D	Policy for Pressure Vessels and Pressurized Systems	

Document Number	Document Name	Applicability Comments
NASA-STD-8719.9A	Lifting Standard	*Reference *The need for compliance with this standard at contractor installations performing NASA work should be evaluated and made a contractual requirement where deemed necessary by the contracting officer, the responsible NASA installation/program safety office, and the Lifting Device Equipment Manager. For on-site operations at NASA facilities, the requirements within this standard are imposed via center-level institutional lift requirements.
NASA-STD-8739.9	Software Formal Inspections Standard	Reference
NASA-STD-8739.8	Software Assurance Standard	Reference Chapters 6, 7.1, 7.2.2, 7.2.3, 7.2.4, 7.3, 7.4, and 7.5.3 (software provider).
NASA-STD-8739.12	Metrology and Calibration	Reference 1.2.2, 1.2.3, 1.3.1, 3.2, Section 4, Appendix A
NASA-STD-6008	NASA Fastener Procurement, Receiving Inspection, and Storage Practices for Spaceflight Hardware	Reference for control of fasteners
NPR 8715.6B	NASA Procedural Requirements for Limiting Orbital Debris and Evaluating the Meteoroid and Orbital Debris Environments	Reference With the exception of flights under licensure by other Federal Agency that has authority to oversee orbital debris mitigation, the following paragraphs apply: P.2, 1.3.2, 1.3.6, 2.4, 3.1.1-3.1.2, 3.1.3, 3.1.4, 3.2.1-3.2.4, 3.2.7, 3.2.8, 3.2.10 (applicable only for return-to-Earth scenarios), 3.2.11, 3.3.1 (applicable to missions orbiting Earth, Moon, or

Document Number	Document Name	Applicability Comments
		Mars or in the vicinity of Sun-Earth or Earth-Moon Lagrange Points), 3.3.2 (applicable to Earth-orbiting spacecraft), 3.3.3 (applicable to missions around the Moon or Mars or in the vicinity of Sun-Earth or Earth-Moon Lagrange Points), 3.3.4-3.3.6, and 3.4.1 (applicable for controlled, commanded, or targeted reentries only).

3 HLS Program Objectives

The list below contains the objectives for HLS reflecting a typical reference mission from Lunar Orbit to the Lunar Surface and back to Lunar Orbit. The offerors solutions must satisfy this list of objectives, as well as the functional and performance requirements listed in section 4 of this document.

Identifier	Title	Statement	Rationale
HLS-Obj-001	HLS Crew Size –Initial	The initial HLS will support a minimum of two crew as a sortie mission without pre-deployed assets.	Initial missions to the lunar surface may only allow for two crew members, therefore HLS should support a minimum of two crew. The mass for two crew with EVA suits, GFE support hardware and consumables will be no greater than 1,000 kg. Mass and volume breakout will be provided in the HLS requirements. There will be no pre-deployed assets.
HLS-Obj-002	HLS Habitation Capability	The initial HLS will provide a habitable environment for 8 earth days without pre-deployed assets.	HLS will sustain the crew throughout the sortie mission, which will include a 6.5 earth day stay on the lunar surface. The initial mission will not include pre-deployed assets.
HLS-Obj-003	Crew Transfer	The HLS will accommodate the transfer of crew and cargo between HLS and a crewed staging vehicle for lunar surface missions.	The current conops describe the Orion taking crew and cargo to the Gateway, nominally in the NRHO, crew and cargo transferring to the Human Lunar System, completing a lunar surface mission, then returning to the Gateway. Other orbits for the transfer of crew and cargo to HLS may be considered but sustained missions will require the use of Gateway in NRHO.
HLS-Obj-004	HLS Automated Rendezvous & Docking	The HLS will provide automated rendezvous and docking.	The HLS will need to be able to rendezvous with and dock to other vehicles even when crew are not present.

Identifier	Title	Statement	Rationale
HLS-Obj-005	HLS Sustainability	Beyond the initial HLS missions, the HLS will support sustainable presence on the Moon by providing a regular cadence of reliable transportation services for humans and cargo.	The agency is committed to the development of a sustainable lunar exploration architecture.
HLS-Obj-006	Surface Access -Initial	The initial HLS will provide crew transfers between Lunar Orbit and a landing site located between 84°S and 90°S, and from the landing site to Lunar Orbit.	Initial landing site will be at the lunar South Pole.
HLS-Obj-007	HLS Operations -Initial	The initial HLS will be capable of operating in continuous daylight conditions on the lunar surface.	The HLS is not required to operate throughout the lunar night or in permanently shadowed regions. HLS may experience brief periods of darkness during lunar occultation (in orbit). The initial mission will be designed to avoid lunar surface eclipses.
HLS-Obj-008	HLS Automated Operations	The HLS will provide the capability to perform automated transfers between Lunar Orbit and the lunar surface, and from the lunar surface to Lunar Orbit.	Automated round-trip transfers are needed to reduce the workload on the crew. The nominal operations are automated for landing.

Identifier	Title	Statement	Rationale
HLS-Obj-009	Science Experiment and Technology Demonstration Accommodation	The HLS will accommodate at least 100 kg of science experiments and technology demonstrations, including at least 20 kg of return mass to Lunar Orbit.	The HLS is intended to support diverse science activities and support closure of Strategic Knowledge Gaps. Down mass 100 kg and up mass of 20 kg is inclusive of tare. Additional details provided in the HLS requirements.
HLS-Obj-010	EVA Capability	The HLS will provide the capability for EVA excursions on the lunar surface.	The HLS EVA capability is needed for lunar exploration, scientific data collection, sample return and to support external contingency maintenance operations. The HLS will provide for EVA system demonstrations, and payload and utilization needs. EVAs may be nominal (pre-planned prior to the crewed mission) or contingency (responding to an off-nominals scenario which arises during the mission).
HLS-Obj-011	Human Performance Capability	The HLS will provide vehicle design and capabilities to enable effective and efficient crew performance throughout the mission.	The HLS will include the human as an integrated part of the overall system throughout all phases of the mission under both nominal and off-nominal conditions. By harnessing human capabilities through human-centered design, the system with enable the crew to control hazards, identify and manage risks, resolve contingencies, recover from hazardous situations, and successfully complete mission objectives in a timely manner.
HLS-Obj-001a	HLS Crew Size - Sustained	The HLS will support a minimum of four crew as a sortie mission.	The HLS will nominally support a crew of four, driven by nominal Gateway capacity. Four crew require predeploy assets to stay more than 12 hours on the surface and to perform an EVA. Surface duration will vary based

Identifier	Title	Statement	Rationale
			on HLS cargo and maturity of surface infrastructure.
HLS-Obj-006a	Surface Access - Sustained	The HLS will provide global lunar surface access for round trip crew and cargo transfers from the Gateway.	HLS will be capable of missions ranging from equatorial to polar regions in sustained operations.
HLS-Obj-007a	HLS Operations - Sustained	The HLS will survive eclipse periods with pre-emplaced surface infrastructure.	Longer duration surface missions will require the HLS to survive periods of eclipse. Details of eclipse survivability are addressed in Level 2 requirements.

4 HLS Functional and Performance Requirements

The following requirements are for the HLS initial 2024 (Option A) and sustained 2026 (Option B) capabilities. These requirements address the "what" to build, and are the functional and performance requirements derived from the objectives in section 3 of this document and through analysis. Offerors shall develop unique, innovative, and cost-effective HLS solutions that achieve NASA's overarching objectives while meeting the following required performance requirements.

4.1 Functional and Performance Requirements – Initial

HLS-R-0070 Daylight Operations - Initial

The initial HLS shall be capable of operating in continuous daylight conditions on the lunar surface.

Rationale: The initial mission will be designed to avoid lunar night, eclipse and occultation, such that the HLS will not need to survive periods of darkness on the surface.

HLS-R-0048 EVA Excursion Duration - Initial

The initial HLS shall be capable of supporting EVA excursions lasting a minimum of 4 hours.

Rationale: EVA excursion includes two suited crew, and begins when crew switch from HLS power to suit power, and ends when cabin repress is initiated upon return of crew. Nominal EVA excursion is 6 ± 2 hrs; lower end of that duration is the requirement for initial configuration. Final determination on duration of EVAs will be made by the science and surface operations team. HLS repress time must be compatible with GFE EVA resources in order to fully comply with requirement to support EVA excursions.

HLS-R-0318 HLS Operations Mass Delivery from Lunar Orbit - Initial

The HLS shall deliver 865 kg (threshold) and 965 kg (goal) from Lunar Orbit to the lunar surface in accordance with the Departure Mass and Volume Allocation Table 8.

Rationale: The 865 kg is based on delivery of two crew, and government furnished equipment for high-level surface operations, but surface mission refinements will set final value.

Table 8: Detailed Descent Mass

Desig.	System	Hardware	CBE Mass (kg)	Volume (m^3)	Power (W)
1.1	EVA	xEMU	373.20	EVA Interface requirement specified under other functional requirements	
1.2	EVA	xEMU Ancillary Equipment and Spares	22.60		
1.3	EVA	xEMU Tools	21.30		
1.4	EVA	Mounted Interfaces & Equipment	94.90		
2.1	Crew Health & Performance	Food	58.87	0.20	
2.2	Crew Health & Performance	Radiation Detector	4.03	0.01	
3.1	Crew Systems	Clothing*	6.97	0.04	
3.2	Crew Systems	Hygiene Supplies*	3.75	0.01	
3.3	Crew Systems	Crew Personal Effects*	5.00	0.01	10
3.4	Crew Systems	Operational Supplies	6.50	0.02	20
4.1	Waste Manamgement	WMS	31.26	0.04	5
5.1	Crew	2 X 90th % Crew	175.30		
6.1	Manager's Reserve	Manager's Reserve	61.32	0.08	5

** allocation - specific items selected by crew*

TOTAL ALLOCATION	865.00

HLS-R-0319 HLS Operations Mass Delivery Return to Lunar Orbit - Initial

The HLS shall return at least 525 kg from the lunar surface to Lunar Orbit in accordance with the Ascent Mass and Volume Allocation Table 9.

Rationale: Required mass to be carried based on return of two crew, and government furnished equipment for current, high-level surface operations approach but surface mission refinements will set final value. 500kg assumes the xPLSS is discarded before ascent. It is an agency preference that the xPLSS be returned if possible. Assume an xPLSS return mass budget of 205kg for a total ascent mass of 705 kg. This mass reflects return after a nominal surface mission.

Table 9: Detailed Ascent Mass

Desig.	System	Hardware	CBE Mass (kg)	Volume (m^3)	Power (W)
1.1	EVA	xEMU	166.90	EVA Interface requirement specified under other functional requirements	
1.2	EVA	xEMU Ancillary Equipment and Spares	12.60		
1.4	EVA	Mounted Interfaces & Equipment	94.90		
2.1	Crew Health & Performance	Food	18.44	0.06	
2.2	Crew Health & Performance	Radiation Detector	4.03	0.01	
3.1	Crew Systems	Clothing*	6.17	0.04	
3.2	Crew Systems	Hygiene Supplies*	3.75	0.01	
3.3	Crew Systems	Crew Personal Effects*	5.00	0.01	10
3.4	Crew Systems	Operational Supplies	6.50	0.02	20
5.1	Crew	2 X 90th % Crew	175.30		
6.1	Manager's Reserve	Manager's Reserve	31.41	0.08	5

** allocation - specific items selected by crew*

TOTAL ALLOCATION	525.00

HLS-R-0324 HLS Habitation Capability - Initial

The initial HLS shall provide a habitable environment for two crew for an 8 earth day lunar sortie without pre-emplaced surface infrastructure.

Rationale: In the initial architecture, no pre-emplaced surface assets will be available at the landing site. The HLS will provide all habitability functionality throughout the sortie. This will drive consumables requirements, as well.

HLS-R-0306 Surface Access - Initial

The HLS shall provide crew transfers to and from Lunar Orbit and a lunar landing site between 84°S and 90°S.

Rationale: Initial surface location is the lunar South Pole. Note: DTE communications from lunar polar locations are subject to multi-path issues and blockages, due to the low angle of Earth over the horizon. DTE communications requires line of site from the HLS landed element to Earth. This condition is highly variable at the lunar poles, with DTE loss of signal (LOS) periods being a dynamic condition. Communications coverage from Gateway will therefore be crucial for providing adequate AOS communication time for the EVA crew. Reference HLS Concept of Operations document section Surface Communications.

HLS-R-0001 HLS Reliability - Initial

The HLS shall have a minimum system hardware reliability of 0.975 for an 8 Earth-day sortie mission to the lunar surface including at least two (threshold) and five (goal) Lunar surface EVAs, without corrective repair for the entire sortie.

Rationale: The scope of the requirement includes the HLS hardware reliability associated with must work and must not work functions starting from initial checkout of HLS in Lunar Orbit prior to crew launch until the crew departure from Lunar Orbit. Software was explicitly excluded and hardware reliability does not consider damage due to MMOD environment or human actions associated with its operation. Also, hardware reliability does not consider fire or medical risk. HLS hardware reliability includes HLS hardware for the defined mission environment includes loads, thermal, radiation etc. required to support performance of the 5 (goal) EVAs (e.g. Airlock cycles), but does not include the reliability associated with the EVA suit.

HLS-R-0004 Failure Tolerance to Catastrophic Events

The HLS shall provide at least single failure tolerance for the control of catastrophic hazards, with the specific level of failure tolerance (one or more) and implementation (the use of similar or dissimilar redundancy) derived from an analysis of hazards, failure modes, and risk associated with the system.

Failure tolerance capability is without the use of: aborts; emergency equipment and systems; or corrective maintenance.

Note: Additional details are provided in HEOMD-003, section 5.2.2.

Exemption A: Failure of primary structure, structural failure of pressure vessel walls, and structural failure of pressurized lines are exempted from the failure tolerance requirement provided the potentially catastrophic failures are controlled through a defined process in which approved standards and margins are implemented that account for the absence of failure tolerance.

Exemption B: Other potentially catastrophic hazards that cannot be controlled using failure tolerance are exempted from the failure tolerance requirements with mandatory concurrence from the HLS Program Manager and the HLS Program Technical Authorities provided the hazards are controlled through a defined process in which approved standards and margins are implemented that account for the absence of failure tolerance. For selected cases where use of a reliability-informed approach is required, as agreed by the HLS Program Manager and HLS Program Technical Authorities, the reliability requirements shall be verified with appropriate confidence intervals using robust reliability approach that is substantially anchored in actual test data verifying margins to environments (natural and induced), life requirements, operational boundaries, and failure modes.

Rationale: The overall objective is to provide the safest design that can accomplish the mission, given the constraints imposed on the Program. Since a HLS development will always have mass, volume, schedule, and cost constraints, choosing where and how to apply failure tolerance requires integrated analyses at the system level to assess safety and mission risks.
First and foremost, when failure tolerance is practical, the failure tolerance is applied at the overall system level - to include all capabilities of the system. While failure tolerance is a term frequently used to describe minimum acceptable redundancy, it may also be used to describe two similar systems, dissimilar systems, dissimilar down mode, cross-strapping, or functional interrelationships that ensure minimally acceptable system performance despite failures, or additional features that completely mitigate the effects of failures. Even when assessing failure tolerance at the integrated system level, the increased complexity and the additional utilization of system resources (e.g. mass, power) required by a failure tolerant design may negatively impact overall system safety as the level of failure tolerance is increased.
Ultimately, the level and type of redundancy (similar or dissimilar) is an important and often controversial aspect of system design. Since redundancy does not, by itself, make a system safe, it is the responsibility of the engineering and safety teams to determine the design that optimizes safety given the mission requirements and constraints. In such a design, both the risk from individual contributors (e.g., hazards or failure modes) and the total risk for the reference mission are below acceptable levels.

HLS-R-0021 HLS Landing Accuracy

The HLS shall be capable of landing within 100m (3-sigma) of target landing site.

Rationale: The HLS is expected to be able to land within an accessible distance of preselected surface destinations in order to optimize EVA resources, scientific objectives, fuel consumption, vehicle navigation capabilities, and crew schedule. The agency has determined that 100 m, or less, is an appropriately accessible distance that will optimize mission resources. Accuracy better than 100m will be subject to evaluation.

HLS-R-0322 Quiescent Lunar Orbit Operations

The HLS shall be capable of maintaining quiescent operations for no less than 60 days (threshold) and 90 days (goal) at Lunar Orbit.

Rationale: The Crew will not launch until HLS is confirmed operational in Lunar Orbit. The HLS may need to remain in Lunar Orbit for 90 days after the HLS is confirmed operational, to await crew and cargo delivery, including potential launch scrubs and mission delays.

HLS-R-0042 Surface Operations

The HLS shall be capable of operating on the lunar surface for a minimum of 6.5 Earth days.

Rationale: The optimal Near Rectilinear Halo Orbit for a sustained architecture has a period, apolune and perilune that drives the architecture to a 6.5 day surface stay capability.

HLS-R-0050 EVA Excursions Per Sortie

The HLS shall be capable of supporting at least two (threshold) and five (goal) surface EVA excursions per sortie.

Rationale: Exploration and Science mission objectives require that the system be capable of two (threshold) and five (goal) *excursions per sortie, inclusive of one contingency EVA.*

HLS-R-0055 HLS Lunar Orbit Insertion

The HLS shall be capable of autonomous lunar orbit insertion.

Rationale: The HLS will need to insert into Lunar Orbit upon completion of TLI and upon ascent from Lunar Surface.

HLS-R-0056 Scientific Payload Return to Lunar Orbit

The HLS shall be capable of returning scientific payload of at least 35 kg and 0.07 m^3 volume (threshold) and 100 kg and 0.16 m^3 volume (goal), inclusive of tare, in accordance with the mass, volume, dimension and environments parameters specified in Table 10, from the South Pole to Lunar Orbit.

Rationale: Empty sample return containers are assumed to have a mass of 20 kg (goal), each with dimensions of at least 48 cm x 30 cm x 20 cm with an expected return of at least 2 containers (goal).

Table 10: Scientific Payload Return

Items	Qty	Mass (kg)	Storage Environment	Geometry	Length (cm)	Height (cm)	Width (cm)	Volume (m3)	Notes
Up Mass Total (Goal)		**100**							
Sample Return Equipment		20						0.16	total volume of all containers.
sample return container	2		Pressurized	box	48	30	20		Dimensions are for each container, 0.06 m3 for both
sample return collection bags	7		Pressurized	box	42	22	15		Dimensions are for each container, 0.1 m3 for all
Lunar Samples		80	Pressurized						would be contained in the Sampler Return volumes above
Up Mass Total (Threshold)		**35**							
Sample Return Equipment		9						0.07	total volume of all containers.
sample return container	1		Pressurized	box	48	30	20		Dimensions are for each container
sample return collection bags	3		Pressurized	box	42	22	15		Dimensions are for each container
Lunar Samples		26	Pressurized						would be contained in the Sampler Return volumes above

Note: Orion does not have specific storage to match the HLS sample return volume. Sample return mass to Eath via Orion might require mission-by-mission decisions on storage within Orion and possible considerations for different sample return container/bag design.

HLS-R-0058 Abort to Crewed Staging Vehicle (CSV)

The HLS shall be capable of conducting a safe return and dock to the crewed staging vehicle within lunar orbit in the event of an abort.

Rationale: The agency requires crewed vehicles to have the capability to abort to a safer location. For the case of a lunar sortie mission, the requirement is for the crewed vehicle to be able to return to lunar orbit for rendezvous and dock. Astrodynamic considerations may dictate that the HLS provide a "shelter in place" capability until the next available launch window presents itself. For the purpose of this requirement abort is defined as : Abort: Same as Mission Abort. The forced early return of the crew to the crewed staging vehicle when failures or the existence of uncontrolled catastrophic hazards prevent continuation of the mission profile and a return to the crewed staging vehicle is required for crew survival.

HLS-R-0061 Automated Missions

The HLS shall be capable of conducting an automated landing on the lunar surface and return to Lunar Orbit.

Rationale: Automated landing is required to reduce crew workload during critical operations.

HLS-R-0314 Operational Cabin Pressure Range

The HLS shall be capable operating with a cabin pressure that ranges from the vacuum of space to a maximum of 15.2 psia max design pressure.

Rationale: EVAs will require open hatch HLS operations on the lunar surface. Therefore, the HLS must be able to operate at all cabin pressures between space vacuum and 14.7 psia, nominal, which requires the capability to operate at 15.2 psia, the maximum design pressure. The HLS must operate in all pressure scenarios—from the vacuum of space to a nominal operating pressure of 14.7 psia—which drives to a max design pressure of 15.2 psia, and thus, the HLS must be capable of operating at all those pressures.

HLS-R-0090 High Resolution Imagery Capability

The HLS shall have the capability to provide interior and exterior still and motion imagery with associated audio and metadata, to the crew and to Mission Systems, during all mission phases.

Rationale: The agency has established a strategic objective of capturing imagery of critical mission events for scientific, verification, safety, anomaly resolution, public affairs and crew health and medical purposes. The functionality is expected to be available during all mission phases, but does not imply continuous exercise of that functionality.

HLS-R-0356 Scientific Payload Delivery from Lunar Orbit

The HLS shall be capable of delivering scientific payload of 100 kg and 1.42 m^3 volume, inclusive of tare, in accordance with the mass, volume, dimension and environments allocations specified in Table 11, from Lunar Orbit to the South Pole.

Rationale: HLS-R-0056 requires science payload and Sample Return. Empty sample return containers are assumed to have a mass of 20 kg, each with dimensions of at least 48 cm x 30 cm x 20 cm with an expected return of at least 2 containers.

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Table 11: Scientific Payload Delivery

Items	Qty	Mass (kg)	Storage Environment	Geometry	Length (cm)	Height (cm)	Width (cm)	Volume (m3)	Notes
Down Mass Total		**100**							
Science Equipment		80							
long axis of tools such as rakes or drive tubes		60-70	Unpressurized	box	145	165	50	1.2	Tools, cameras and sensors will remain on lunar surface
cameras or other sensors for use in the habitable environment	2	10-20	Pressurized	box	48	38	18	0.06	Dimensions are for each container, 0.06 for both
Sample Return Equipment*		20						0.16	total volume of all containers.
sample return container	2		Pressurized	box	48	30	20		Dimensions are for each container, 0.06 m3 for both
sample return collection bags	7		Pressurized	box	42	22	15		Dimensions are for each container, 0.1 m3 for all

*Sample Return Equipment would be empty during descent and used to carry lunar samples back to Gateway during ascent. During descent, they could be filled with other items. In the event that full return mass goal is not met and the full complement of sample return equipment is not needed, the remainder of the allocation of down mass and volume will be filled with additional science items.

HLS-R-0029 Concurrent RF Communication

The HLS shall be capable of concurrent RF communications with lunar orbiting crew, Mission Systems, and Suits.

Rationale: HLS operations may require the capability to communicate with an EVA excursion, mission systems and the orbiting crew at the same time.

HLS-R-0304 HLS Automated RPODU- Initial

The HLS shall be capable of automated rendezvous, proximity operations, docking and undocking with a crewed staging vehicle (threshold) and both crewed staging vehicles (goal).

Rationale: The HLS will need RPODU capability to transfer crew and cargo to and from HLS. Threshold: the HLS must dock with at least one of the crewed staging vehicle (Orion with an active docking mechanism or Gateway with a passive docking mechanism), Goal: The HLS must have the ability to dock with both Gateway (passive) and Orion (active). Contractors can choose to meet the goal by using an AADA or have an androgynous docking mechanism. RPODU operations will be detailed in the relevant IRD.

HLS-R-0108 Manual Control

The HLS shall provide the capability for the crew to manually control the flight path and attitude.

Rationale The capability for the crew to control the spacecraft's flight path is a fundamental element of crew survival and mission success. A minimum implementation of manual control for lunar landing allows the crew to bypass the automated guidance of the vehicle to affect flight path. In addition, a minimum

implementation for RPODU allows for manual attitude control. Selection of an alternate landing site/target is an expected capability of an automated landing system, however, limiting the crew to choices presented by the automated guidance function is not a valid implementation of manual control.
The intent of this requirement is to provide the crew the ability to take control of the spacecraft, especially during critical phases, if there are issues with the automated system (failures or unexpected performance) to (1) protect crew survivability and (2) enable mission success. Applied to a lunar lander, the most critical phase is the actual terminal descent and landing on the lunar surface that is populated with landing zone hazards. An automated flight control system will be a closed loop system continuously working toward a precision landing at the designated landing site while performing landing zone hazard detection, analysis, and avoidance during the terminal landing phase. One possible implementation of this requirement for a lunar lander would be that the crew can exit the closed loop automated software and algorithms that are making the decisions on both precision landing and hazard avoidance while then making the key inputs to manually control/fly the spacecraft to avoid hazards and achieve a safe and successful landing. A specific example for this terminal landing phase would be the crew controlling descent, lateral and longitudinal drift rates with automation likely handling other facets of the vehicle control such as vehicle attitude. These would be considered "blended" manual control solutions and other blended solutions may exist. Other critical phases of flight include undock/back-away from Gateway to start the lunar sortie and the approach/rendezvous return to Gateway to complete the lunar sortie. Reference BAA Attachment A17 CA-19-23 Human Landing Systems White Paper for Manual Control Systems.

Note: Manual control cannot be safely or accurately performed without the spatial and situational awareness tools to provide status, feedback, and flight control direction. Safe operation requires both accuracy of crew inputs and Level 1 handling qualities to meet human rating requirements. Tools include, but are not limited to, telemetry, displays, video, instrumentation, and windows. Manual control implementation and the supporting tools will be verified in a cockpit environment to ensure they are adequate to support manual control and operations appropriate for the lunar lander.

HLS-R-0109 Remote operations

The HLS shall provide the capability for the crewed staging vehicle, and Mission Systems, to monitor, operate, and control the HLS elements and subsystems remotely, when

a) The remote capability is necessary to execute the mission; or
b) The remote capability would prevent a catastrophic event; or
c) The remote capability would prevent an abort.

Rationale: To meet agency human rating requirements for space vehicles, the HLS must provide the capability to be operated remotely for the specified conditions.

HLS-R-0110 Fault Isolation and Control

The HLS shall provide the capability to isolate and recover from faults identified during system development or mission operations that would result in a catastrophic event

Rationale: To meet agency human rating requirements for space vehicles, the HLS must provide the capability isolate and control identified faults.

HLS-R-0071 Landing Site Vertical Orientation

The HLS shall provide vertical orientation of 0 to 8° (threshold) and 0 to 5° (goal) from local vertical for surface operations.

Rationale: The HLS must support all post-landing crew activities. It is expected that the slope tolerance (landed stability) of the HLS will exceed the acceptable lander tilt angles for the safe and effective execution of critical crew functions during the lunar surface mission. As a result, some means of tilt mitigation may be required. Critical crew habitation operations impacted by lander attitude include EVA suit don/doff, EVA suit undock and re-dock to donning stand, IVA mobility, eating, sleeping, hygiene, as well as operation and maintenance of equipment. Critical EVA operations impacted by lander attitude include hatch ingress/egress, lander "deck" activities (e.g. dust mitigation), descent element platform translation between the hatch and the ladder, ladder descent/ascent, transition between the ladder and the lunar surface, transport of tools/equipment to the lunar surface, access to externally stowed tools/equipment, transport of lunar samples/sample containers to the ascent element, and assistance to impaired or recovery of an incapacitated crew member (e.g. rescue from the surface to the interior of the ascent element).

HLS-R-0073 Window(s) for Crew Tasks

The HLS shall provide one or more window(s) for crew use through all phases of flight that provides direct, non-electronic, through-the-hull viewing and the unobstructed field-of-view necessary to perform critical crew viewing tasks.

Rationale: During descent and landing, and RPOD (rendezvous, proximity operations, and docking), the crew must check the performance of automatic systems and ensure landing zone hazard avoidance. A suite of electronic sensors, cameras and window(s) support automatic and blended automatic/manual control capabilities. Windows increase crew safety and mission success probability by enabling critical crew viewing functions:

1. Provide situational & spatial awareness for the crew to monitor the automated system and make Go/No-Go decisions until touchdown for landing, or until docking contact for RPOD

2. Provide cues to confirm the Landing Zone location, and that it is clear of hazards prior to touchdown

3. Provide cues for the crew to validate acceptable descent, lateral and longitudinal drift rates throughout terminal descent until touchdown for landing or until docking contact for RPOD

4. Provide cues to confirm HLS is within the docking cone, is in proper attitude, and that the two vehicles remain in alignment until docking interface contact and capture

5. Provide insight enabling crew re-designation of an alternate landing target

6. Support manual/blended control if primary automated system degrades or fails

4.2 HLS Functional and Performance Requirements- Sustained

The following "sustained" requirements will supersede the "initial" requirements listed above. The requirements below have the same number as the initial requirements followed by "a".-The requirements below are intended to address the increased functionality of the HLS for the 2026 demonstrations and beyond.

HLS-R-0304a HLS Automated RPODU - Sustained

The HLS shall be capable of automated rendezvous, proximity operations, docking and undocking with Gateway (threshold) and both crewed staging vehicles (goal).

Rationale: The HLS will need RPODU capability to transfer crew and cargo to and from HLS. Threshold: the HLS must dock with Gateway with a passive docking mechanism and Goal: The HLS must have the ability to dock with both Gateway (passive docking mechanism) and Orion (active docking mechanism). Contractors can choose to meet the goal by using an AADA or have an androgynous docking mechanism. RPODU operations will be detailed in the relevant IRD.

HLS-R-0002 HLS Reliability (cumulative) - Sustained

The HLS shall have a minimum system hardware reliability of 0.87 over the life of the program with corrective maintenance of reusable elements for sustaining missions.

Rationale: This requirement does not envelope the initial (2024) mission, it is for the sustainability phase. The HLS reusable elements are expected to support at least 5 designed mission uses over a 10 year period. The period between reuse may be up

to 3 years. Reusability is not required for the 2024 mission, however by 2028, at minimum the ascent module should be reusable. The scope of the requirement includes the HLS hardware reliability associated with must work and must not work functions for the life of the program. The analysis does not include transport of HLS elements to Gateway. Software was explicitly excluded because there is not a standard methodology for performing software reliability. Hardware reliability does not consider damage due to MMOD environment or human actions associated with its operation. Defined mission environment includes loads, thermal, radiation etc. HLS hardware reliability includes HLS hardware required to support performance of the EVAs required per mission (e.g. Airlock cycles) but does not include the reliability associated with the EVA suit which is not considered HLS hardware. Hardware reliability does not consider fire or medical risk.

HLS-R-0027 HLS Reliability (per mission) -Sustained

Each of the lunar sorties shall have a minimum per mission reliability of .98 from Gateway separation to Gateway return.

Rationale: This requirement does not envelope the initial (2024) mission, it is for the sustainability phase. The HLS must maintain a minimum reliability for each follow on mission which may increase mission objectives (such as longer duration) that will require a robust hardware reliability improvement task. The HLS reusable elements are expected to support at least 5 designed mission uses over a 10 year period. The period between reuse may be up to 3 years. Reusability is not required for the 2024 mission, however by 2028, at minimum the ascent module should be reusable. The scope of the requirement includes the HLS hardware reliability associated with must work and must not work functions for the life of the program. The analysis does not include transport of HLS elements to Gateway. In addition, HLS allocated hardware reliability supports HLS compliance with program-level Loss of Crew and Loss of Mission requirements. Software was explicitly excluded because there is not a standard methodology for performing software reliability. Hardware reliability does not consider damage due to MMOD environment or human actions associated with its operation. Defined mission environment includes loads, thermal, radiation etc. HLS hardware reliability includes HLS hardware required to support performance of the EVAs required per mission (e.g. Airlock cycles) but does not include the reliability associated with the EVA suit which is not considered HLS hardware. Hardware reliability does not consider fire or medical risk.

HLS-R-0070a Daylight Operations - Sustained

The HLS shall be capable of surface operations during 50 hours (threshold) and 191 hours (goal) of continuous darkness.

Rationale: In the sustained architecture, the HLS will be required to survive periods of lunar night, periods of eclipse and periods of occultation.

HLS-R-0048a EVA Excursion Duration - Sustained

The HLS shall be capable of supporting EVA excursions lasting a minimum of 8 hours.

Rationale: EVA excursion includes two suited crew, and begins when crew switch from HLS power to suit power, and ends when cabin repress is initiated upon return of crew. Nominal EVA excursion is 6 ± 2 hrs; upper end of that duration is the requirement for sustained configuration. Final determination on duration of EVAs will be made by science and surface operations team.

HLS-R-0318a HLS Mass Delivery from Gateway - Sustained

The HLS shall deliver at least 1,595 kg from the Gateway to the lunar surface.

Rationale: Level I transportation scope requires delivery to lunar surface. Required mass of cargo to be carried based on current, high-level surface operations approach but surface mission refinements will set final value. Evolution to sustained capability may include a 3-crew option, and a delivery mass of 1,205 kg.

HLS-R-0319a HLS Operations Mass Delivery Return Gateway - Sustained

The HLS shall return at least 1,070 kg from the lunar surface to Gateway.

Rationale: Level I transportation scope requires return from lunar surface, Required mass of cargo to be carried based on current, high-level surface operations approach but surface mission refinements will set final value. Evolution to sustained capability may include a 3-crew option, and a return mass of 815 kg.

HLS-R-0324a HLS Habitation Capability - Sustained

The HLS shall provide a habitable environment for a four crew lunar sortie with pre-emplaced surface infrastructure, but is still expected to provide EVA excursions (two suited crew per excursion) as specified in HLS-R-0050 EVA Excursions Per Sortie.

Rationale: In a sustained architecture, pre-emplaced surface assets will be available at the landing site. The HLS is not expected to provide all habitability functionality throughout the sortie. Note: The definition of EVA excursion does not change in the sustained architecture. An EVA excursion is "two suited crew".

HLS-R-0306a Surface Access - Sustained

The HLS shall provide global lunar surface access for round trip crew and cargo transfers from the Gateway.

Rationale: HLS will be capable of missions ranging from equatorial to polar regions in sustained operations. Specific mission profiles will be defined on a site-by-site basis to determine appropriate surface durations while maintaining manageable energy requirements and while considering mission support roles from other available government lunar assets. The HLS will be capable of operating in a range of thermal and solar environments as dictated by the latitude and longitude of the sites selected however considerations will be made for local surface topography

5 Verification

This section will contain any formal qualification requirements that are necessary to show compliance. Proposed detailed verification methodologies and expectations for Crewed Systems can be found in Appendix C.

Appendix A External Interfaces

This Appendix contains NASA's current understanding of the HLS interfaces that the providers should address within their proposal. The HLS integrated lander must successfully interface with these systems. The Offeror's proposal must:

(1) Utilize these interface definitions as defined in Appendix A **or**

(2) Propose interfaces that fully meet the intent defined in Appendix A

Since xEMU suits and Gateway are being developed simultaneously, there are TBDs/TBRs within the interface requirements. Where possible, the government has provided a number via analysis with a TBR to assist the offeror in creating a FFP. The majority of the TBRs should be resolved December 2019. The offeror will have the opportunity to adjust price after the CBR if any interface requirements affect their proposal price.

NOTE: Interoperability functionality (Initial) will be captured in Gateway to Visiting Vehicle (VV) Interface Definition Document (IDD) Human Landing System (HLS) Interface Requirements Annex (HLS IRD-001) or HLS to Orion IRD (HLS-IRD-005), HLS EVA Systems IRD (EVA-EXP-0067), and HLS EVA Compatibility IRD (EVA-EXP-0070). The intent of the interoperability standards must be addressed for demonstration of sustainability.

HLS-R-0500 Orion to HLS Interface
The HLS shall interface with Orion in accordance with HLS-IRD-005.

Rationale: Vendors that propose to use Orion as the Crew Staging Vehicle will need to design an HLS that will exchange crew, payload, power, data, commands and atmosphere with Orion when attached.

HLS-R-0312 Gateway to HLS Interface

The HLS shall interface with the Gateway in accordance with the Gateway Visiting Vehicle (VV) Interface Definition Document (IDD) Human Landing System (HLS) Interface Requirements Annex (HLS IRD-001).

Rationale: Vendors that propose to use Gateway as the Crew Staging Vehicle will need to design an HLS that will exchange crew, payload, power, data, commands and atmosphere with Gateway when attached.

HLS-R-0310 HLS to Mission Systems

The HLS shall interface with Mission Systems in accordance with Human Landing Systems to Mission Systems Interface Requirements Document (HLS-IRD-004)

Rationale: The HLS shall exchange data and commands with mission control.

HLS-R-0311 HLS to Suit System

The HLS shall interface with the Surface Suits in accordance with EVA-EXP-0067 HLS-Suit System Interface Requirement Document.

Rationale: Surface Suits are Government Furnished Equipment (GFE), and will be used for descent, EVA excursions, and ascent. The HLS must be designed to accommodate the interface with the Surface Suits for stowage, operation, crew translation, cleaning, refresh, and disposal. The IRD will specify the interface and the resources required for use.

HLS-R-0323 HLS EVA Compatibility

The HLS shall interface with the Exploration EVA System in accordance with the EVA-EXP-0070 HLS EVA Compatibility Interface Requirement Document (IRD)

Rationale: EVA interfaces are designed to be compatible with EVA operations. This includes restraining the crewmember, safeguarding both the vehicle and crewmember while working, and accommodating EVA operations using a standard EVA tool set. This document can be tailored by the EVA Office for HLS to include an applicability matrix for each element.

Appendix B Safety, Reliability, and Maintainability Standards

This Appendix provides detailed technical standards extracted from NASA Safety standard HEOMD-003 Crewed Deep Space Systems Certification Requirements and Standards for NASA Missions (DRAFT). These standards set forth a potential approach for how NASA would design, build, certify, and operate an HLS. These standards are offered in this Appendix as a starting point for the Offeror's proposal for all work to be performed through the end of the contract. The Offeror's proposal shall:

(1) Demonstrate that the proposal meets or exceeds each NASA standard

(2) Employ an alternative approach to a specific standard which the Offeror asserts is equivalent in outcome, with a thorough explanation of such equivalency and a rationale in support of this approach in lieu of NASA's specification (i.e., a "meets the intent of" approach); and/or

(3) On a case-by-case basis, provide an approach that does not meet a particular NASA standard or its intent, but results in a demonstrably better approach that is more likely to enable the Offeror's ability to achieve one or more of NASA's overarching objectives and functional performance requirements as set forth in section 3 and 4 of this document.

HLS-SMA-0005 Mitigate Hazardous Software Behavior

The HLS shall provide the capability to mitigate the hazardous behavior of critical software where the hazardous behavior would result in a catastrophic event.

Rationale: Mitigation of software hazardous behavior occurs on two levels. 1) Where software functionality is used to control hazards in systems or hardware (i.e. monitoring/control, data integrity checks, inhibits, two-step commands, etc.), and 2) where the erroneous execution of software results in a hazard (i.e. logic error, divide by zero, etc.). This requirement is met in 2 parts: 1) system hazard analysis with implementation/verification of hazard controls in software functionality. 2) Mitigation of potential anomalies in executable code through development of software according to NPR 7150.2C (NASA Software Engineering Requirements).

HLS-SMA-0006 Autonomous Systems

The HLS shall provide the capability for autonomous operation of system and subsystem functions, which, if lost, would result in a catastrophic event.

Rationale: This capability means that the HLS crewed system does not depend on communication with Earth (e.g., mission control) to perform functions that are required to keep the crew alive, (i.e., HLS "critical' systems are autonomous, where a critical

system is defined as a system whose behavior or performance could lead to a catastrophic event or abort. Also includes the flight software and ground-control software. Autonomous is defined as: the ability of a space system to perform operations independent from any ground-based systems.).

HLS-SMA-0007 Detect and Annunciate Faults

The HLS shall provide the capability to detect vehicle faults affecting critical systems, subsystems, or crew health and annunciate these conditions to operators and crew.

Rationale: It is necessary to alert the both earth crew and flight crew to faults (not just failures) that affect critical functions. A fault is defined as an undesired system state. A failure is an actual malfunction of a hardware or software item's intended function. The definition of the term "fault" envelopes the word "failure," since faults include other undesired events such as software anomalies and operational anomalies.
Note: Monitoring of crew health status is addressed separately using GFE.

HLS-SMA-0008 Monitor Controls and Inhibits

The HLS shall monitor and provide, to flight and earth crews, the status of controls and inhibits associated with functions whose inadvertent activation, and those functions whose failure to activate when required, could have catastrophic results.

Rationale: Controls are hardware and software features provided to mitigate (reduce the likelihood of) the cause of a catastrophic hazard. Inhibits are a special implementation of hazard controls for safety-critical functions, which disable the functions. Monitoring controls and inhibits ensures they are functional and effective at all times. In addition, monitoring provides situational awareness of the state of the vehicle and the risks presented by a change in the status of these controls. Flight and earth crew can use this knowledge to support actions to move to a less hazardous state or inform decisions while operation in this state.

HLS-SMA-0009 Health and Status Data for Anomaly Resolution

The HLS shall provide the capability to utilize health and status data (including system performance data) of critical systems and subsystems to facilitate anomaly resolution during and after the mission.

Rationale: Access to health and status data is a key element of anomaly resolution during the mission, which could prevent the crew from executing an abort or prevent the situation from developing into a catastrophic event.

HLS-SMA-0010 Manual Override of Higher-Level Software Control/Automation

The HLS shall provide the crew the capability to manually override the higher-level software control/automation (such as automated abort initiation, configuration change, and mode change) when the override of the software system will not directly cause a catastrophic event.

Rationale: This is a specific capability necessary for the crew to control the HLS and ensure crew survival.

While this capability should be derived, the critical nature of software control and automation at the highest system level dictates specific mention. Therefore, the crew has the capability to control automated configuration changes and mode changes, including automated aborts, at the system level as long as the transition to manual control is feasible and will not cause a catastrophic event.

For example, manual override of a mode change could be for RPOD (Rendezvous, Proximity Operations and Docking) to override a state change in the automation relating to the RPOD, either to force the next stage of the RPOD or to prevent moving to the next stage. This may be triggered by a damaged target or a bad RPOD sensor preventing docking and some exterior event (e.g., crew medical emergency) is driving a need to dock urgently. An example of manual override of a configuration change would be for the power system to have some means to isolate a module from one or both main power buses. This requirement recognizes that the crew performs functions to meet mission objectives and, in those cases, the crew is provided the designated capabilities. This does not mean that the crew is provided these capabilities for all elements of a mission. Many considerations are involved in making these determinations, including capability to perform the function and reaction time. Also, that this capability would prevent a catastrophic event or to prevent an inadvertent abort.

NOTE: The appropriate implementation of this requirement is based on hazard analyses with final approval using the hazard approval process.

HLS-SMA-0029 Disposal

The HLS shall be disposed at the end of life in such a way as to not create a credible risk of collision with Gateway or celestial objects. Mission post-deployment trajectory is designed to avoid unplanned impact of any celestial objects by the spacecraft in the next 50 years at the 1x10-2 probability level, and with Mars/Europa/ Enceladus at the 1x10-4 probability level.

Rationale: Disposal should prevent orbital debris around the Moon and Gateway, including the Gateway conjunction orbits. The mission post-deployment trajectory will be designed to avoid unplanned impact of any celestial objects and with Mars/Europa/ Enceladus by the spacecraft in the next 50 years.

Note: NASA will collaborate with Partner to document the disposal method and trajectory.

HLS-SMA-0014 Control Critical Hazards

The HLS shall control critical hazards. The hazard must be controlled without the use of aborts, emergency operations or emergency systems.

Rationale: Critical hazards do not require failure tolerance for human-rating. Failure tolerance may be implemented to meet the HLS reliability requirements.

Note 1: Emergency systems and equipment, such as fire suppression systems, fire extinguishers and emergency breathing masks, pressure suits, and systems used exclusively for launch aborts, should not be considered part of the failure tolerance capability since these emergency systems and equipment cannot definitely prevent a catastrophic initiating event.

Note 2: Emergency equipment and aborts are considered crew survival methods, not controls.

B.1 Reliability

The development of the HLS Program Loss of Crew (LOC) and Loss of Mission (LOM) requirements will be based on an analysis of achievability for the selected mission and capabilities required. Typically, historical data for similar systems, capabilities, and operations is used to estimate an achievable level of risk for the selected mission, and additional margin may be added to account for uncertainties in future design or mission changes. Modeling assumptions and data must be coordinated with the cognizant systems engineering personnel to ensure accuracy and consistency with design and mission assumptions.

HLS-SMA-0030 Micrometeoroid and Orbital Debris (MMOD)

The HLS shall have a Probability of No Penetration (PNP) greater than or equal to 0.99998^(A*Y) where: A = total hazardous impact surface area (m^2) and Y = exposure time in years for items with the potential to create a catastrophic hazard if impacted or punctured by MMOD

Rationale: This requirement sets the limit for the probability of no penetration. Area is the outer most surface area of the module and is in m^2 and Time is in years. Time used for calculation should encompass the expected life of the module. For the purposes of MMOD, a penetration is defined as damage/failure to stored energy devices that causes a hazard to crew or CSV survivability. Typically, penetration is defined as a partial or complete perforation of the pressure vessel or casing, detached

spall from the pressure vessel wall, damage to the pressure vessel that would allow unstable crack growth, or deformation of a casing of rotating machinery such that the deformation could intrude into the dynamic envelope of the rotating device. For metallic tank pressure vessels, critical damage is defined as a penetration depth in the pressure shell of 20% of the thickness of the pressure shell. For composite overwrapped pressure vessels, critical damage is defined as penetration of 90% of the composite overwrap thickness. Solar array panels are not included in this requirement. Risk analysis programs used to calculated PNP such as Bumper code (NASA TM-2009-214785) quantify the probability of penetration of shielding and the damage to spacecraft equipment as a function of the size, shape, and orientation of the spacecraft; the parameters of its orbit; and the impact damage resistance of each spacecraft. The meteoroid environment is defined in NASA/TM-2015-218214, NASA Meteoroid Engineering Model Release 3.0 (Description: https://www.nasa.gov/offices/meo/software/mem_detail.html) (Software request: https://www.nasa.gov/offices/meo/software/meo_form.html) , and the orbital debris environment is defined in NASA/TP-2015-218592, NASA Orbital Debris Engineering Model 3.0 (Description: https://orbitaldebris.jsc.nasa.gov/modeling/ordem-3.0.html)(Software request: https://software.nasa.gov/software/MSC-25457-1). This requirement sets the limit for the probability of no penetration.

B.2 Maintainability

Maintenance for the initial mission (e.g., 2024) is not envisioned. For future missions, the sustained HLS capabilities are expected to introduce reusability of some systems, thereby opening the possibility for some in-space maintenance, which should be considered during the design process. The development of the maintenance capability for the sustained missions will be based on analysis of the capabilities required for achieving the selected missions. The solution must consider available tools and accessibility to system hardware, and minimize crew tasks so the crew is not overwhelmed by maintenance activities. Both maintenance and repair must reflect the limits of logistics for spares and limited life items in order to achieve the optimal system availability.

HLS-SMA-0011 Maintainability-Initial

The HLS shall be designed for no planned maintenance activities during the lunar sortie.

Rationale: Given the short mission duration for the initial (demonstration) mission, there is limited free time available for maintenance activities. This requirement does not prohibit design for maintainability as contingency operations would be much easier with those design features (e.g., crew accessibility, common parts, etc.).

HLS-SMA-0028 Maintainability - Sustained

The HLS shall be designed for on orbit maintenance (scheduled/preventative and un-scheduled/corrective) to not exceed 24 man-hours in duration, with no maintenance activities during the lunar sorties.

Rationale: Maintenance activities may include removal, replacement, service, and repair of hardware and software. Maintenance must be accomplished by the flight crew utilizing IVA and EVA Common Tool Kits. HLS health monitoring systems telemetry will be utilized to determine spare/repair parts required prior to earth departure.

Appendix C Human Health and Medical Standards

The information contained within Appendix C has been tailored from NASA-STD-3001, NASA Space Flight Human Systems Standard Volume 2, Rev B: Human Factors, Habitability, and Environmental Health, and NASA-STD-3001: NASA Space Flight Human Systems Standard Volume 1 Rev A: Crew Health, to assist the contractor in focusing on areas specific to the 2024 Human Lander mission.

This Appendix provides detailed technical standards. These standards set forth a potential approach for how NASA would design, build, certify, and operate an HLS. These standards are offered in this document as a starting point for the Offeror's proposal for all work to be performed through the end of the contract. The Offeror's proposal shall:

(1) Demonstrate that the proposal meets or exceeds each NASA standard

(2) Employ an alternative approach to a specific standard which the Offeror asserts is equivalent in outcome, with a thorough explanation of such equivalency and a rationale in support of this approach in lieu of NASA's specification (i.e., a "meets the intent of" approach); and/or

(3) On a case-by-case basis, provide an approach that does not meet a particular NASA standard or its intent, but results in a demonstrably better approach that is more likely to enable the Offeror's ability to achieve one or more of NASA's overarching objectives and functional performance requirements as set forth in section 3 and 4 of this document.

HLS-HMTA-0001 Design Using Human-Centered Task Analysis

The provider shall use a task analysis to support hardware and operations design.

Rationale: A detailed task analysis of crew required activities is required to determine appropriate human spacecraft designs and layout along with the appropriate operational activities. This task analysis is utilized by numerous other standards such as error assessment, net habitable volume, cognitive workload, situational awareness, display design, information management, EVA suit mobility, etc.

HLS-HMTA-0002 Accommodate Physical Characteristics of Crew

The system shall accommodate the physical characteristics and capabilities as provided by NASA in Physical Characteristics and Capabilities Data Set.

Rationale: 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 include characteristics and capabilities such as, anthropometric dimensions, body joint/segment range of motion, strength (minimum & maximum), mass, volume, and surface area. Factors that affect human characteristics and capabilities, such as sex, age, physical condition, environment (e.g., reduced gravity, posture, pressurized suit), etc., are identified and included in the datasets. Based on task analysis definition of task-affecting parameters, design parameters (e.g., minimum design force, range of hip breadth, etc.) are to be selected from NASA datasets. NASA provides datasets for specific programs and/or systems under design depending on program lifecycle, design reference mission, concept of operation, and other factors.

HLS-HMTA-0003 Muscle Effects

The effects of muscle endurance and fatigue should be factored into system design.

Rationale: Tasks with high force requirements and repetitive tasks (even with low force requirements) can cause fatigue. Additionally, since spaceflight can decrease muscle size, muscle strength, muscle power, and muscle endurance, these factors are to be considered in system design. Program requirements are to ensure that designers have accurate data of the strength of crewmembers in anticipated fatigued conditions. A fatigued crewmember should be able to perform any requested task.

HLS-HMTA-0004 Aerobic Capacity

The system should be operable by crewmembers with the aerobic capacity as defined in NASA-STD-3001, Volume 1.

Rationale: Aerobic capacity information is an important engineering number, and program requirements are to ensure accurate data are available to system developers. The aerobic capacity in conjunction with the operational concept provides an upper bound for oxygen (O2) demand, carbon dioxide (CO2) production, heat rejection requirements, etc. This information is vital for all spacecraft Environmental Control and Life Support System (ECLSS) designs, including the extravehicular activity (EVA) suits. This information would help in sizing the primary and emergency O2 systems, scrubbers, etc., and help the engineers perform trade studies on various suit designs based on the operational scenarios and metabolic expenditure.

HLS-HMTA-0005 Perception and cognition capabilities

The system should accommodate crewmember perception and cognitive capabilities

Rationale: These requirements articulate human perceptual and cognitive characteristics from a functional, i.e. task performance, perspective. 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 spaceflight can further degrade human capabilities. Systems need to be designed to support human perceptual and cognitive capabilities to meet system performance requirements.
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.

HLS-HMTA-0006 Visual Capabilities

Visual capabilities should be accommodated in the design of all visual interface elements for anticipated levels of crew capability and anticipated levels of 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 crew capability and anticipated levels of task demands is based on a detailed task analysis.

HLS-HMTA-0007 Auditory Perceptual Capabilities

Auditory perceptual capabilities should be accommodated in the design of all auditory system elements that interface with the crew for anticipated levels of crew capability and anticipated levels of task demands.

Rationale: 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) and to accommodate suited versus unsuited conditions, e.g., headset versus loudspeaker conditions. Determination of anticipated levels of crew capability and anticipated levels of task demands can be made through a detailed task analysis.

HLS-HMTA-0008 Sensorimotor Capabilities

Sensorimotor capabilities should be accommodated in the design of all display-control system elements that interface with the crew for anticipated levels of crew capability and anticipated levels of task demands.

Rationale: 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.

HLS-HMTA-0009 Cognitive Capabilities

Cognitive performance capabilities should be accommodated in the design of all system elements that interface with the crew for all anticipated levels of crew capability and all anticipated levels of task demands.

Rationale: Accommodating cognitive performance capabilities is important to ensure optimal task performance and crew safety. Design of hardware, including displays and controls, are 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. This is especially important during spaceflight, where microgravity can cause deconditioning and affect spatial orientation, radiation can induce acute cognitive deficits, 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.

HLS-HMTA-0010 Time and Performance

The ability to perform tasks in a timely and accurate manner shall be accommodated in the design of all system elements that interface with the crew for anticipated levels of crew capability and anticipated levels of task demands.

Rationale: Factors to be considered in design include, but are not limited to: time to complete the task; time to train for the task; consequence and time to recover from errors; the nature, type (e.g., independent versus team tasks) and environmental conditions of the task; and the state of the human and the team (e.g., deconditioned, lack of adaptation to microgravity, sleep deprived). Some prominent aerospace accidents have been traced to the human's inability to perform emergency operations

under the time demands and environmental challenges present, emphasizing the need for design that integrates crew capability with task demands. Determination of anticipated levels of crew capability and anticipated levels of task demands is based on a detailed task analysis.

HLS-HMTA-0011 Situational Awareness (SA)

Systems shall provide the SA necessary for efficient and effective task performance and provide the means to recover SA, if lost, for anticipated levels of crew capability and anticipated levels of task demands.

Rationale: Lack of SA has been associated with numerous accidents and incorrect decisions by flight crews in commercial aviation and in Earth-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.

HLS-HMTA-0012 Nominal Cognitive Workload

The system shall provide crew interfaces that, when used to perform nominal crew tasks, result in Bedford Workload Scale ratings of 3 or less (or equivalent rating on another validated workload scale).

Rationale: Metrics of cognitive workload measure the mental demands required of a person to perform a given task. Appropriate workload levels keep the crewmember engaged in the task, while allowing spare mental capacity to deal with concurrent tasks or issues. Some of the most safety-critical decisions and actions associated with operating a spacecraft are carried out in situations where the crew is multi-tasking, processing numerous inputs, and making decisions concerning multiple, possibly unrelated, problems. Work may also demand abrupt shifts between tasks performed alone and tasks relying on others' inputs. Likewise, environmental stressors such as radiation and altered atmospheric composition or pressure may impede the ability to adapt to changes in cognitive workload. Excessive workload demands on any one task can cause the operators to exclusively focus on one problem or approach to performing the tasks, leaving little or no spare capacity to deal with any other problems that may occur. Therefore, having designed a human-system interface to support a crew task, designers are to assess the operation as part of a human-in-the-loop simulation to determine the workload associated with that operation. If the

cognitive workload is judged to be so high that a human has little or no spare capacity to deal with a concurrent problem, the task and supporting interfaces are to be redesigned. The Bedford Workload Scale has been selected by NASA as the workload verification method for a number of program workload requirements, as of the publication of this volume. However, the NASA Task Load Index (TLX) may be preferred for developmental testing, due to its diagnostic properties. Other validated indicators of workload may be used by programs with approval from the Health and Medical Technical Authority.

HLS-HMTA-0013 Off-Nominal Cognitive Workload

The system shall provide crew interfaces that when used to perform off-nominal crew tasks result in a Bedford Workload Scale rating of 6 or less (or equivalent rating on another validated workload scale).

Rationale: During off-nominal events, it is important to ensure crewmembers' workload is not excessively high. High workload can leave an operator with little or no spare mental capacity to contend with additional demands that, during an off-nominal situation, could have significant negative outcomes. The Bedford Workload Scale has been selected by NASA as the workload verification method for a number of program workload requirements, as of the publication of this volume. However, the TLX may be preferred for developmental testing, due to its diagnostic properties. Other validated indicators of workload may be used by programs with approval from the Health and Medical Technical Authority.

HLS-HMTA-0014 Shirt Sleeve Environment

The system should maintain a shirt sleeve environment in all habitable volumes during crewed missions.

Rationale: A safe, breathable atmosphere is critical to crew health and performance. Monitoring atmospheric quality, alerting MCC and crew of off-nominal conditions, and evaluating environmental data trends during vehicle flight operations is essential to crew health support. The vehicle system needs to be robust enough to control or allow crew control of atmospheric pressure, humidity, temperature, ventilation flow rate, airborne particulates, partial pressure of O2, CO2, and trace contaminants within ranges necessary to maintain human health and safety.

HLS-HMTA-0015 Trend Analysis of Environmental Data

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, and radiation (see sections 6.2 through 6.8 of NASA-STD-3001 Vol 2, Rev B 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.

HLS-HMTA-0016 Inert Diluent Gas

For mission durations in excess of 2 weeks, the atmosphere shall contain a physiologically inert diluent gas to prevent lung collapse.

Rationale: A diluent gas, in addition to O2, is required in nominal, long-duration, breathable atmospheres to prevent lung collapse, in addition to reducing the ignition/flammability threshold. The choice of diluent gas is dependent on many factors, including physiological activity and contribution to decompression sickness (DCS).
Diluent gas percent or concentration will be driven by overall pressure profile of the vehicle, and further bounded by oxygen flammability limits established for the pressure profiles under consideration. Reference 3001 Volume 2 6.2.1.2. O2 Partial Pressure Range for Crew Exposure for hyperoxic/hypoxic limits. Clinically significant atelectasis ("lung collapse") is unlikely below the hyperoxic bounds established in Table I.

HLS-HMTA-0017 O2 Partial Pressure Range for Crew Exposure

The system shall maintain inspired oxygen partial pressure (PIO2) as per table 12.

Rationale: For all systems, the range of ambient dry-gas ppO2 should be considered in the context of PIO2. Spaceflight systems designed for humans should be normoxic unless strong rationale is provided for an alternative suggestion. For HLS missions with the primary goal of completing EVA, sufficient rationale is provided in HLS-L2-HMTA-0031 Decompression Sickness (DCS) Risk Mitigation. Extensive operational experience from shuttle and ISS with PIO2 of 127 mmHg show no evidence of degraded health or performance in astronauts over 7 days. There is no indication on Earth that living and working with chronic PIO2 of 127 mmHg degrades health or performance. There are no indications or predictions based on limited past experience that extending exposure time with PIO2 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. 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 ½ an atmosphere of O2 partial pressure (Clarke, J.M., Oxygen Toxicity

(Chapter 6). In: 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 ppO2 of 7.35 psia, or 380 mmHg, or as PIO2, it is 333 mmHg. These guiding PIO2 values may change as further research yields information to better define the physiological limits and acceptable duration for an alternative spaceflight system environment.

Table 12: Inspired O2 Partial Pressure Exposure Ranges

Inspired O_2 partial pressure $P_IO_2 = (P_B\text{-}47)\times F_IO_2$	Normoxia Target Range	Mild Hypoxia Lower Limit	Indefinite Hyperoxia Upper Limit	Short Term Hyperoxia Upper Limit
P_IO_2 (mmHg) **$P_IO_2 = (P_B\text{-}47)\times F_IO_2$**	145-155	127	356	791
P_IO_2 (psia)	2.8-3.0	2.5	6.9	15.3
Acceptable Duration	Indefinite	30 days with monitoring **	Indefinite	6-9 Hours *
Examples	Habitat and Spacesuit Minimum	EVA Preparation (ISS Campout, Shuttle 10.2 psia and 26.5% O_2, Exploration Atmosphere of 8.2 psia and 34% O_2)	EVA and Cabin Depress In-Suit Survival	O_2 Prebreathe for EVA Preparation

P_B – Ambient Barometric Pressure in mmHg

F_IO_2 – The dry-gas decimal fraction of ambient O_2 (ex. 21% = 0.21)12182003

*From 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 9 hours when that is the only exposure to enriched O_2 in a 48-hour period. The limit is 6 hours when it is the only exposure to enriched O_2 in a 24-hour period and also states that consecutive daily exposures shall not exceed 5 consecutive days.

**There is no opportunity to collect data in microgravity with P_IO_2 of 127 mm Hg to cover the durations of Exploration Class missions, so a health monitoring and mitigation plan are required to implement this condition

HLS-HMTA-0018 Nominal Vehicle/Habitat Carbon Dioxide Levels

The system shall limit the 1-hour average partial pressure of carbon dioxide (ppCO2) in the habitable volume to <3 mm Hg.

Rationale: Achieving this level is dependent on individual and total crew generation of CO2 for all planned activities (factoring in metabolic rates and respiratory quotient)

appropriate CO2 scrubbing and adequate ventilation flow rates to ensure that no localized pockets of CO2 are generated throughout the habitat.
Off-nominal CO2 values are not included at this time and will be negotiated based on expected human performance, duration of exposure, access to medical care, etc.

HLS-HMTA-0019 Ventilation Rate

The system shall maintain a ventilation rate within the internal atmosphere such that two-thirds (66.7%) of the atmosphere velocities are between 4.57 m/min (15 ft/min) and 36.58 m/min (120 ft/min), 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 CO2 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. 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 CO2 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 in order to protect the safety of the crew.]
As general guidance the engineering teams should be aware of crew metabolic loads that drive scrubbing rates of the ECLSS. The following table from the Human Integration Handbook (HIDH) https://www.nasa.gov/feature/human-integration-design provides that guidance.

HLS-HMTA-0020 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 ≤ 103 kPa (3.8 psia < pressure ≤ 15.0 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 ppO2. Oxygen-rich atmospheres, however, present safety hazards because of their ability to feed fires. The lowest

pressure at which normoxia (PIO2 = 149 mmHg) is maintained at 100% O2 is 3.8 psia. Total pressure has to be considered in conjunction with O2 and CO2 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.

HLS-HMTA-0021 Rate of Pressure Change

The rate of change of total internal vehicle pressure shall not exceed 13.5 psi/min.

Rationale: The rate of change of pressure is to be limited to prevent injury to crewmembers' ears and lungs during depressurization and repressurization. The positive rate of change limit is designed to prevent barotraumas in spaceflight conditions, where 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 dive manual. The negative rate of change limit is consistent with the U.S. Navy dive manual 13.5 psi/min (700 mmHg/min) (30 ft/min) ascent rate allowance.

HLS-HMTA-0022 Relative Humidity

Average relative humidity (RH) shall be maintained between 25% and 75% over each 24-hour period during all mission operations, excluding suited operations of less than 8 hours.

Rationale: Average humidity is to be maintained above this lower limit (25%) to ensure that the environment is not too dry for the nominal functioning of mucous membranes and to prevent static electricity buildup within the cabin, which could pose an increased electrical hazard to people. Average humidity is to be maintained below this upper limit (75%) for crew comfort and to limit formation of condensation. Excess moisture in the glove can contribute to trauma at the fingertips. Considerations are to be given for expected elevations in RH such as during exercise.

HLS-HMTA-0023 Comfort Zone

The system shall be able to maintain thermal conditions in the comfort zone as shown in Figure 1, Environmental Comfort Zone (ref NASA-STD-3001 Vol 2, Rev B), throughout all mission phases, including planned contingencies.

Rationale: The comfort zone is defined as the range of environmental conditions, e.g., temperature and RH, in which humans can achieve thermal comfort and not have their performance of routine activities affected by thermal stress. Thermal comfort is affected by the work rate, clothing, and state of acclimatization. This combination of environmental conditions is important to define, since humidity and temperature requirements may be met separately but together may be outside of the comfort zone.

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-STD-3001, Vol 2, Rev B.

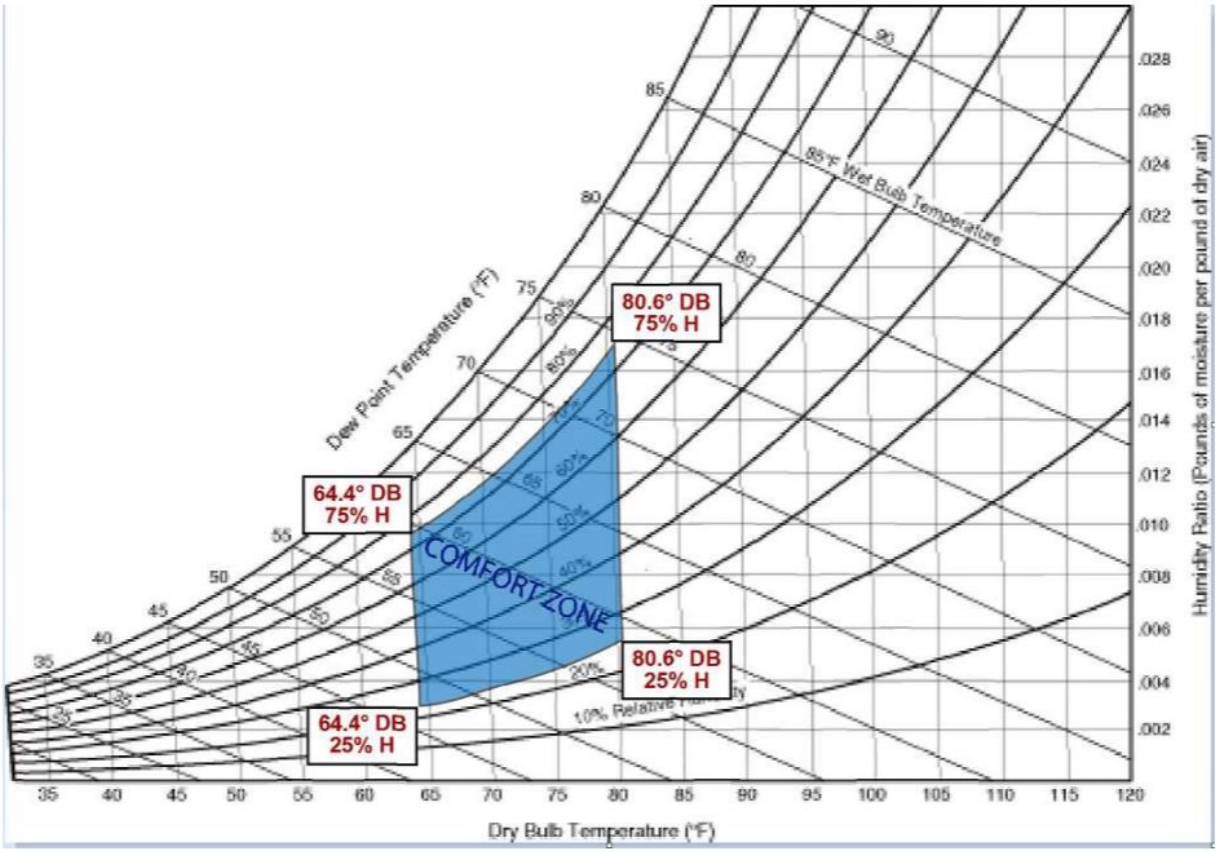

Figure 1: Environmental Comfort Zone

HLS-HMTA-0024 Temperature Comfort Range

The system should maintain the atmospheric temperature within the range of 18 ºC (64.4 ºF) to 27 ºC (80.6 ºF) during all nominal operations, excluding suited operations.

Rationale: This temperature range is defined as the range of environmental conditions in which humans can achieve thermal comfort and not have their performance of routine activities affected by thermal stress.

HLS-HMTA-0025 Atmospheric Control

The system shall allow for local and remote control of atmospheric pressure, humidity, temperature, ventilation, and ppO2.

Rationale: The ability to control atmospheric conditions is important for crew comfort, e.g., temperature and humidity, and for mission tasks, e.g., ppO2 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 section 11.4, Suited Atmospheric Control [V2 11033], in this NASA-STD-3001 Vol 2, Rev B. 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, celestial body surfaces, or Earth- or lunar-based control centers.

HLS-HMTA-0026 Atmospheric Data Recording

For each isolatable, habitable compartment, the system shall automatically record pressure, humidity, temperature, ppO2, and ppCO2 data.

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 section 11.5, Suited Atmospheric Data Recording [V2 11034], in this NASA-STD-3001 Vol 2, Rev B.

HLS-HMTA-0027 Atmospheric Data Displaying

The system shall display real-time values for pressure, humidity, temperature, ppO2, and ppCO2 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 section 11.6, Suited Atmospheric Data Displaying [V2 11035], in this NASA Technical Standard.

HLS-HMTA-0028 Atmospheric Monitoring and Alerting

The system shall monitor atmospheric parameters, including atmospheric pressure, humidity, temperature, ppO2, and ppCO2 and alert the crew locally and remotely 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-STD-3001 Vol 2, Rev B for additional information. This requirement does not apply to spacesuits.

HLS-HMTA-0414 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.

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, substances that may build up during quiescent operations, or substances that are not normally thought of as part of the atmosphere. Accepted limits may be based on 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.

HLS-HMTA-0029 Combustion Monitoring and Alerting

The system shall continuously monitor toxic atmospheric components per Volatile Combustion Product Monitoring in Spacecraft, TOX-VER-2016-03, that would result from pre-combustion and combustion events before, during, and after the event and alert the crew in sufficient time for them to take appropriate action.

Rationale: Monitoring and alerting are required to identify when toxic components are detected and to alert the crew so they can take appropriate actions to maintain health and safety. Because of the extreme danger of combustion in a spacecraft, alerting is to occur quickly enough, e.g., within 5 seconds, to allow the crew to address the hazard, e.g., locating and using a fire extinguisher.

HLS-HMTA-0030 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.

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), nitrogen tetroxide/nitrogen dioxide and ammonia, need to be monitored after EVA.

HLS-HMTA-0031 Decompression Sickness (DCS) Risk Mitigation

The system shall achieve the level of acceptable risk of DCS as defined in NASA-STD-3001, Volume 1, Section 4.4.3.6.1, Decompression Sickness Prevention.

Rationale: The planned operations and system design must protect crew from decompression sickness (DCS) related to pressure changes for EVA operations (including preparation and return) and off-nominal depressurization situations. DCS risk limits are defined in NASA-STD-3001 Volume 1 paragraph 4.4.3.6.1 Decompression Sickness (DCS) Prevention. DRAFT Lunar Prebreathe Table is below.

Table 12a Draft Lunar Prebreathe Table

DRAFT Lunar Prebreathe Table

	Scenario 1	Scenario 2	Recommended Scenario 3	Scenario 4	Scenario 5
Gateway Atmosphere *	14.7, 21% O_2	10.2 psi, 26.5% O_2	10.2 psi, 26.5% O_2	14.7 psi, 21% O_2	14.7 psi, 21% O_2
Lander *** Atmosphere	10.2 psi, 26.5% O_2	10.2 psi, 26.5% O_2	8.2 psi, 34% O_2	14.7 psi, 21% O_2	8.2 psi, 34% O_2
Prebreathe prior to and/or during descent?	1+ hours TBR (on mask, or in-suit)	None required	None required	None	3+ hours TBR (on mask, or in-suit)
Minimum time in Lander prior to EVA	Longer prebreathe if EVA prior to 36 hours	No constraint	No constraint after 24 hours Small PB penalty if earlier than 24hrs	None	Longer prebreathe if EVA prior to 36 hours
Estimated O_2 prebreathe prior to EVA **	Estimate 3-3.5 hours TBR	Estimate 3-3.5 hours TBR	Estimate 0 -30 mins TBR	Estimate 6.5-7 hours TBR	Estimate 0 -30 mins TBR

Assumed Conops***	
Orion transit to Gateway	TBD days
Orion docked to Gateway	5 days
Lander undock, transit to lunar surface (12 hrs)	Lunar Day 1
Post landing safe-ing & reconfig (~4 hrs)	
Crew Sleep (8 hrs)	
EVA 1	Lunar Day 2
EVA 2	Lunar Day 3
No EVA	Lunar Day 4
EVA 3	Lunar Day 5
EVA 4	Lunar Day 6
Lander ascent, return to Gateway	Lunar Day 7

* Assume 36+ hours at atmosphere prior to lander undocking; balance N2 in all atmospheres

** Estimated prebreathe times are approximations and not validated; assume 6 hour EVA @ 4.3 psia.

*** Assumed Conops requires use of a reduced pressure, O_2 enriched environment to provide staged denitrogenation. Scenario 4 is provided for reference, but would probably not facilitate the assumed Conops

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HLS-HMTA-0032 Decompression Sickness Treatment Capability

The system shall provide a DCS treatment capability by providing a pressure of 156.5 kPa (22.7 psia) (1,174 mmHg) to a DCS affected crewmember via a combination of vehicle and suit pressures within 2 hours of a DCS event and maintained for 6 hours.

Rationale: DCS is a potential hazard of spaceflight 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 O2 therapy. This capability may utilize vehicle and EVA suit resources and design.

HLS-HMTA-0033 Potable Water

The system shall provide potable water for crew use.

Rationale: Potable water is necessary to maintain crew hydration during vehicle operations. Potable water limits are applicable to all points of crew consumption or contact. Points of consumption or contact include any locations from which potable water is dispensed for use in drinking, food rehydration, personal hygiene, and medical needs. Water safety establishes that physiochemical and microbiological limits are met. Quantity of water available in-mission is dependent on usage rates for crew hydration (i.e. drinking, food rehydration, hygiene, medical contingency), mission tasking (e.g. EVA). Water dispensing rates and temperature shall also be factored into design of potable water systems to ensure accuracy and to prevent injury.

HLS-HMTA-0034 Potable Water Physiochemical Limits

The HLS shall provide potable water that is safe for human use, including drinking, food rehydration, personal hygiene, and medical needs and is aesthetically acceptable.

Rationale: This requirement is covered by IECLSSIS (TBC), so verifications can be combined. 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.

HLS-HMTA-0035 Potable Water Microbial Limits

At the point of crew consumption or contact, the system shall provide potable water quality at or below the microbial limits of Table 13, Potable Water Microbiological Limits (ref NASA-STD-3001 Vol 2, Rev B), to the crew for drinking, food rehydration, personal hygiene, and medical needs.

Rationale: This requirement is covered by IECLSSIS (TBC), so verifications can be combined. Microbially safe water is essential to prevent infection and mitigate risk to crew health and performance. 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.

Table 13: Potable Water Microbiological Limits

Characteristic	Maximum Allowable	Units
Bacterial Count	50	CFU/ml
Coliform Bacteria	Non-detectable per 100 ml	-
Fungal Count	Non-detectable per 100 ml	-
Parasitic Protozoa, e.g., Giardia and Cryptosporidium	0	-

Note: CFU = colony forming unit.

HLS-HMTA-0036 Drinking Water Quantity

The system shall provide a minimum water quantity as specified in Table 14: Water Quantity and Temperature for the expected needs of each mission.

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 crew 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. 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. Hot and cold water

temperature ranges in Table 14 are required for systems designed to deliver hot and cold water. The ambient temperature range in Table 14 is required for systems not specifically designed to deliver hot and cold water.

Water is also needed for personal hygiene, which will depend on the mission length, number of crew, and design of the hygiene system. Clean water is necessary for maintaining skin, hair, and dental health of crewmembers. 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 eye and wound irrigation during the various activities of a mission, which is based on experience and data from Shuttle, ISS, and Apollo programs. 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, lithium hydroxide (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 crew, 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 exclusive.

Table 14: Water Quantity and Temperature

Standard	Quantity (*quantities are mutually exclusive)	Temperature		
		Hot	Ambient	Cold
Potable Water for Drinking	2.5 L (84.5 fl oz) per crewmember per day	between 68.3 ºC (155 ºF) and 79.4 ºC (175 ºF)	between 18 ºC (64.4 ºF) and 27 ºC (80.6 ºF)	maximum temperature of 15.6 ºC (60 ºF)
Potable Water Quantity for Food Rehydration	(taken from Potable Water for Drinking)			
Potable Water Quantity for Drink Rehydration	(taken from Potable Water for Drinking)			
Potable Water Quantity for Personal Hygiene	Minimum 400 mL (13.5 fl oz) of potable water per crewmember per day	between 29.4 ºC (85 ºF) and 46.1 ºC (115 ºF)		
Potable Water Quantity for Eye Irrigation	Minimum 500 mL (16.9 fl oz) per crewmember	between 18 ºC (64.4 ºF) and 27 ºC (80.6 ºF)		
Potable Water for Medical Use and Medical Contingency	Minimum of 5.0 L (169.1 fl oz)			
Potable Water for EVA Operations	Minimum 240 mL (8.1 fl oz) per EVA hour			

HLS-HMTA-0037 Water Dispensing Increments

To prevent overflow, water shall be dispensable in increments that are compatible with the NASA provided food/drink bag.

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 increments. All food portions are sized to be compatible with water dispensed in 25ml increments up to 250ml. This requirement is not meant to drive a specific design solution (e.g. perastolic pump).

HLS-HMTA-0038 Water Dispensing Rate

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, 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. On ISS today, water is dispensed at 25 ml increments. All food portions are sized to be compatible with water dispensed in 25ml increments up to 250ml.

HLS-HMTA-0039 Water Temperature

The system should provide the appropriate water temperature as specified in Table 14 Water Quantity and Temperature for the expected needs of each mission and task.

Rationale: Over the course of long-duration missions, crews can tire of repetitive beverages and foods. Providing hot and cold water is an important way of keeping the crew 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 also allows for faster rehydration of beverages and foods, as well as aiding in the prevention of microbial growth.
Also, 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.

HLS-HMTA-0040 Water Treatment Chemicals and Residual Biocides

All chemicals used to treat, purify, or preserve potable water, including residual biocides and disinfection byproducts, shall be controlled to levels that do not adversely affect crew health at the point of crew consumption or contact.

Rationale: Points of crew consumption or contact are defined in the rationale for [HLS-HMTA-0034]. Special consideration should be taken with treatment chemicals and residual biocides as these species may need to be present at levels above allowable exposure limits in order to be effective. 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.

HLS-HMTA-0041 Toxic Hazard Level Three

The system shall use only chemicals that are Toxic Hazard Level Three or below in the habitable volume of the spacecraft.

Rationale: The intent of this requirement is not to limit or restrict the use of materials, e.g., paints that have the potential of outgassing Toxic Hazard Level Three compounds. Rather, the intent is that when such materials are used in the habitable volume of a system, they be controlled in accordance with JSC-20584, Spacecraft Maximum Allowable Concentrations for Airborne Contaminants. Furthermore, Toxic Hazard Level Three and below compounds could pose an immediate risk to human health; therefore, supplies for crew protection and spill containment are to be provided. This would allow for crewmembers to clean contaminated surfaces and atmospheres of Toxic Hazard Level Three and below compounds. In addition to the supplies needed to respond to a spill, the system itself needs to be capable of controlling the contamination below the spacecraft maximum allowable concentration (SMAC) limits defined in section 6.4.2, Atmosphere Contamination Limit – Airborne Contaminants [V2 6050], of NASA-STD-3001 Vol 2 Rev B. However, should a Toxic Hazard Level Three compound be deemed out of control and unable to be cleaned or contained, then the substance is elevated to Toxic Hazard Level Four and treated as such. Toxic Hazard Level ratings are assigned by JSC Toxicology based on information received per V2 6XXX and JSC 27472 Requirements for Submission of Data Needed for Toxicological Assessment of Chemicals and Biologicals to be Flown on Manned Spacecraft.

HLS-HMTA-0042 Toxic Hazard Level Four

The system shall prevent Toxic Hazard Level Four chemicals from entering the habitable volume of the spacecraft.

Rationale: Toxic Hazard Level Four compounds 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 V2 6XXX

and JSC 27472 Requirements for Submission of Data Needed for Toxicological Assessment of Chemicals and Biologicals to be Flown on Manned Spacecraft

HLS-HMTA-0043 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.

Rationale: Only a few compounds have been shown to decompose into hazardous compounds during nominal Atmosphere Revitalization System operations on the Space Shuttle, but these compounds could present a toxic threat if the amount of the compound involved is sufficient and the product compound is hazardous.

HLS-HMTA-0044 Atmosphere Contamination Limit – Airborne Contaminants

The spacecraft shall limit gaseous pollutant accumulation in the habitable atmosphere to below 1.0 T unit during crewed missions based on the individual chemical compound concentration limits established in JSC 20584, Spacecraft Maximum Allowable Concentrations for Airborne Contaminants.

Rationale: A toxic hazard unit, or T-unit, is the sum of the ratios of each predicted/measured pollutant concentration to the respective limit from JSC 20584. Airborne exposure limits for individual trace chemical contaminants and methods for assessing trace contaminant mixtures in a crewed cabin atmosphere are defined to protect crewmembers from illness and injury. The Spacecraft Maximum Allowable Concentrations (SMACs) provide guidance for short-term (1 and 24 hours), medium-term (7 and 30 days), and long-term (180 days and 1000 days) exposure of individual trace chemical contaminants. SMACs take into account unique factors for human space flight including the stress on human physiology and uniform good health of astronauts and the absence of pregnant or very young individuals. Short-term SMACs are designated as emergency SMACs and are intended to be used in emergency situations, such as accidental spills or fire. Medium and long-term SMACs are guidance levels intended to avoid adverse health effects, either immediate or delayed, and to avoid degradation in performance of crew after continuous exposure for the designated duration. For HLS the 30-d SMACs are most appropriate and will be allocated across mission phases.

HLS-HMTA-0046 Particulate Matter

The system shall limit the cabin particulate matter concentration for total dust to <3 mg/m3 with a crew generation rate of 1.33 mg/person-minute, and the respirable fraction of the total dust <2.5 µm in aerodynamic diameter to <1 mg/m3 with a crew generation rate of 0.006 mg/person-minute.

Rationale: These values were derived by applying a factor of 5 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., LiOH or extraterrestrial dust. The factor of 5 is applied to adjust from intermittent occupational exposure to continuous spaceflight exposure. The basis for the particulate matter generation rates is documented in ICES-2019-58. 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.]

HLS-HMTA-0047 Lunar Dust Contamination

The system shall limit the levels of lunar dust particles less than 10 µm in size in any habitable atmosphere below a time-weighted average of 1.6 mg/m3 during daily exposure periods that may persist up to 7 days 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 8 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.

HLS-HMTA-0048 Design for Cleanliness

System surfaces shall be compatible and accessible for cleaning to prevent crew contamination.

Rationale: Engineering out sources of contamination is preferred. As that will not always be possible, it is required that the vehicle must have the ability to be cleaned.

HLS-HMTA-0049 Surface Cleanability

The interior surfaces of the system shall be made from materials that minimize microbial growth and are compatible with in-flight cleaning and disinfection.

Rationale: Internal surfaces of spacecraft and habitats can become contaminated with microorganisms during normal day-to-day use. This requirement is intended to ensure that the internal surfaces of spacecraft and other habitable volumes can be cleaned/disinfected to mitigate the risk of bacterial and fungal contamination. Surface materials should be selected to limit the growth and facilitate in-flight cleaning/disinfection. All surface materials used in habitable volumes should

assessed for cleanability. Materials in areas prone to dirt accumulation (e.g., galley, hygiene areas, donning/doffing areas) should be given special consideration with regard to material selection.

HLS-HMTA-0050 Condensation Limitation

The system shall prevent condensation persistence to less than 1 hour a day on surfaces within the internal volume.

Rationale: The presence of free water in the internal volume 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. For example, current ISS requirements provide some flexibility in allowable condensate persistence for areas determined to have minimal crew health risk.

HLS-HMTA-0051 Microbial Air Contamination Prevention

The system shall limit the levels of microbial contaminants by maintaining a continuous flow of air that has been cleaned to have at least 99.97% of airborne particles 0.3 μm in diameter, or larger, removed.

Rationale: Microbial limits for breathing air are designed to prevent infection and allergic response. The specific air flow rates are dependent on the vehicle design and expected operations. To provide clean air, ISS air systems have relied on High Efficiency Particulate Air (HEPA) filter design, which has performed exceptionally well in controlling atmospheric microbial concentrations.

HLS-HMTA-0052 Cross-Contamination

The system shall control cross-contamination among crew, payloads, e.g., animals and plants, surface vehicles, and planetary environments to acceptable levels in accordance with JPR-1800.5.

Rationale: Contamination from payloads and planetary environments to crewmembers can negatively affect crew health; contamination from crewmembers and planetary environments to payloads can affect scientific data; contamination from crewmembers and payloads to planetary environments may impact the health of the planetary environment, including possible microscopic life forms on the surface.

HLS-HMTA-0053 Availability of Environmental Hazards Information

The system shall make toxicological and environmental hazard information available to 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.

HLS-HMTA-0054 Contamination Cleanup

The system shall provide a means to remove or isolate released 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. For Appendix H, this does not include contaminants caused by GFE payloads.

HLS-HMTA-0055 Accessibility for Cleaning

Sufficient volume shall be provided to access areas that need to be cleaned.

Rationale: The full size range of personnel with appropriate cleaning tools and equipment is to be able to access all areas for routine cleaning. 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 and dirt.

HLS-HMTA-0056 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.

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.

HLS-HMTA-0057 Cleaning Materials

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

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.

HLS-HMTA-0058 Hygiene Equipment Cleanliness

The system shall accommodate an environmentally compatible cleaning and sanitization method for personal hygiene facilities and equipment, including the waste management system.

Rationale: To remain hygienic, personal hygiene equipment must be easily cleaned and sanitized. Cleaning and sanitizing helps control odor and microbial growth. Cleanliness is necessary to prevent disease.

HLS-HMTA-0059 Sustained Translational Acceleration Limits

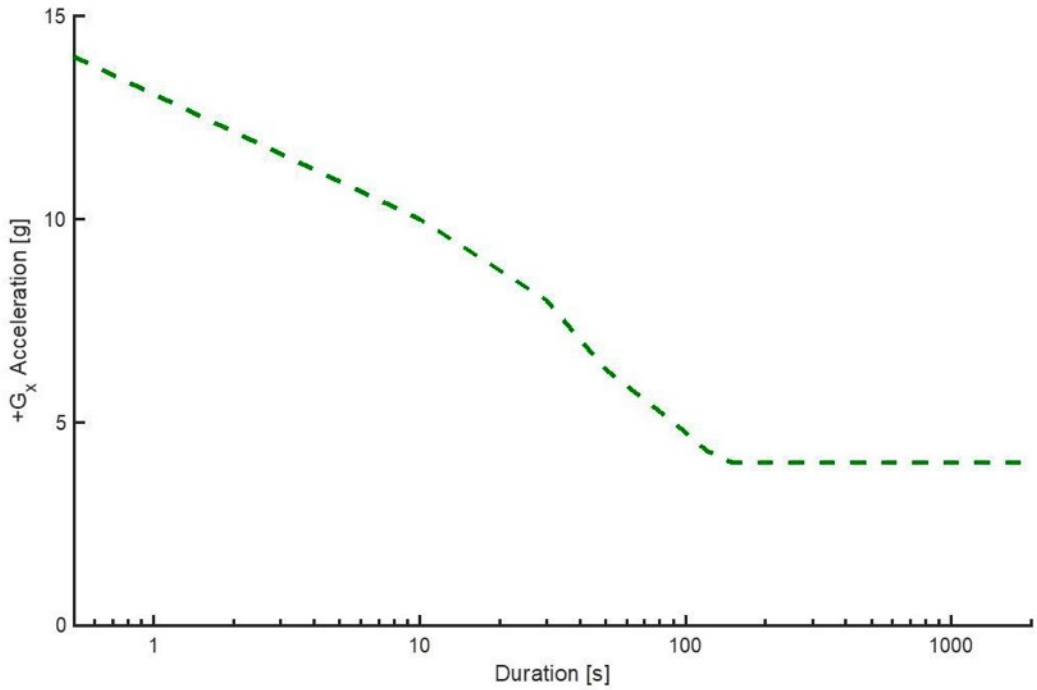
The system shall prevent the crew from being exposed to linear accelerations greater than those depicted in Figure 2, +GX Linear Sustained Acceleration Limits, Figure 3, -GX Linear Sustained Acceleration Limits, Figure 4, ±GY Linear Sustained Acceleration Limits, Figure 5, +GZ Linear Sustained Accelerations Limits (Standing, Short Duration), Figure 6, +GZ Linear Sustained Acceleration Limits (Seated or Standing with Countermeasure, Long Duration), and Figure 7, -GZ Linear Sustained Acceleration Limits.

Rationale: The limits represent the maximum level of sustained acceleration allowed on a crewmember after sustained exposure to a reduced or microgravity environment. After working at the mission destination, crewmembers are expected to have degraded capabilities due to the pathophysiology of deconditioning from exposure to reduced gravity, and therefore should not be exposed to accelerations higher than those depicted. Greater exposure to accelerations than those presented could significantly affect human performance and safety.
All limits assume additional equipment (suit) mass borne by the crewmember is less than 20% of the crewmember's shirt sleeve mass.
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.

A deconditioned crewmember in a seated posture is not comparable to a crewmember in a standing posture; standing significantly increases sensitivity to acceleration in the +Gz axis. Due to the risk of orthostatic intolerance (OI) resulting in crewmember loss of consciousness or impaired crewmember performance, limits for standing posture during dynamic phases of flight are captured for both short (≤ 30 days mission elapsed time) and long (>30 days mission elapsed time) mission profiles in Figure 5, +GZ Linear Sustained Acceleration Limits (Standing, Short Duration) and Figure 6, +GZ Linear Sustained Acceleration Limits (Seated or Standing with Countermeasure, Long Duration). For mission elapsed time >30 days at the time of dynamic loading, standing without the addition of a counterpressure garment to prevent orthostasis is not consistent with the limits presented. Mission elapsed time is defined as the time elapsed from launch to the time of the dynamic event being assessed (e.g. ascent from lunar surface).

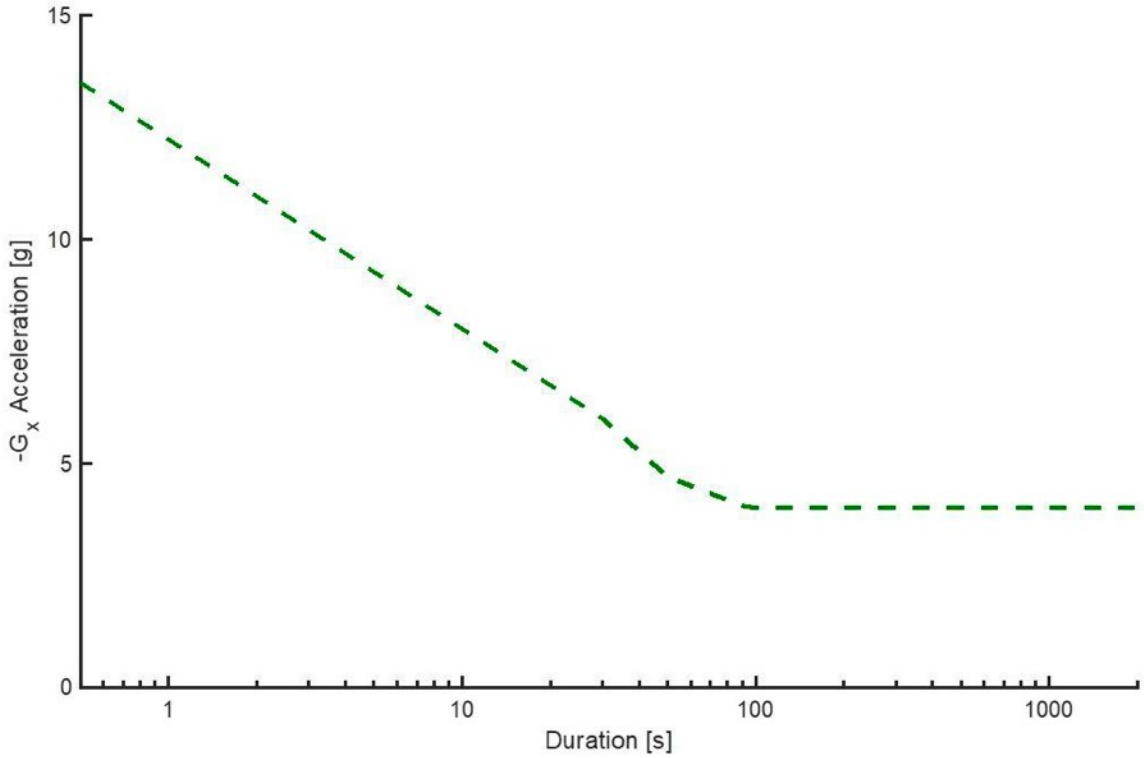
The limits presented here were derived from evaluation of Apollo biomedical and flight profile data during lunar descent and ascent operations (n=12), Soyuz (n=12) and Shuttle (n=138) flight profile and post-landing biomedical data, and analogue bed rest post-exposure data on OI. Both male and female astronaut incidence of post-spaceflight OI has been well characterized, with ~20% of Shuttle astronauts displaying signs of OI following short duration space flight overall. This number rises to >60% in the absence of a counterpressure garment following long-duration space flight. Conversely, the addition of a counterpressure garment significantly augments orthostatic tolerance for short and long duration astronauts of both sexes in both stand and tilt table testing post-flight. Terrestrial analogue data were used to bound longer duration and fractional G (<1.0 Gz) exposure tolerance in both male and female subjects where post-flight data did not exist.

Each axis is to be analyzed separately, and conservatism in the limits for each axis covers any cumulative effect of acceleration in multiple axes.



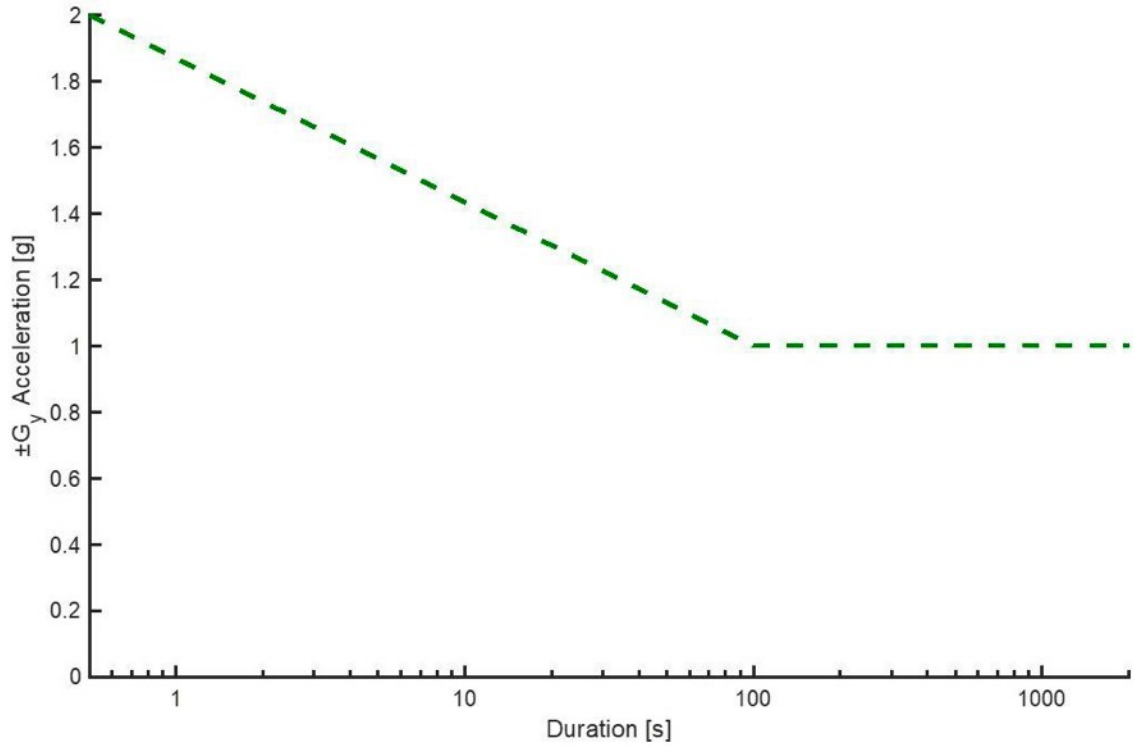
Duration (sec)	0.5	10	30	50	90	120	150	Sustained
Acceleration (g)	14	10	8	6.3	5	4.3	4	4

Figure 2: +GX Linear Sustained Acceleration Limits



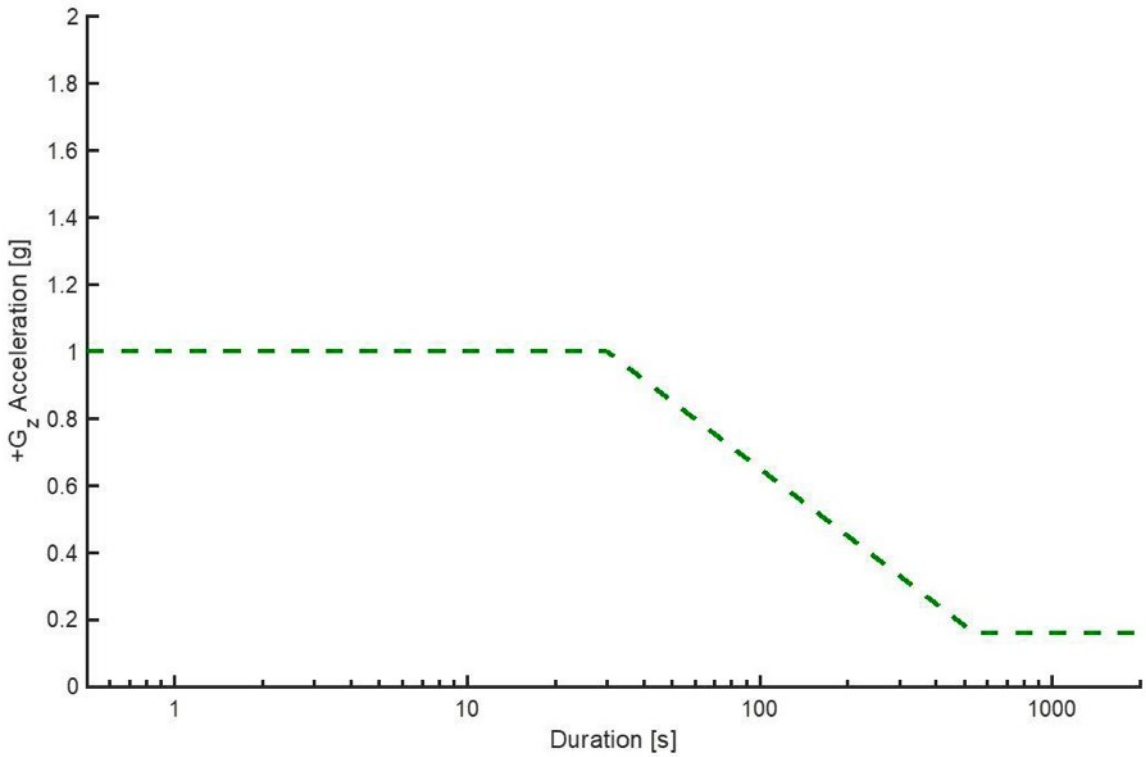
Duration (sec)	0.5	10	30	50	90	100	Sustained
Acceleration (g)	13.5	8	6	4.7	4.05	4	4

Figure 3: -GX Linear Sustained Acceleration Limits



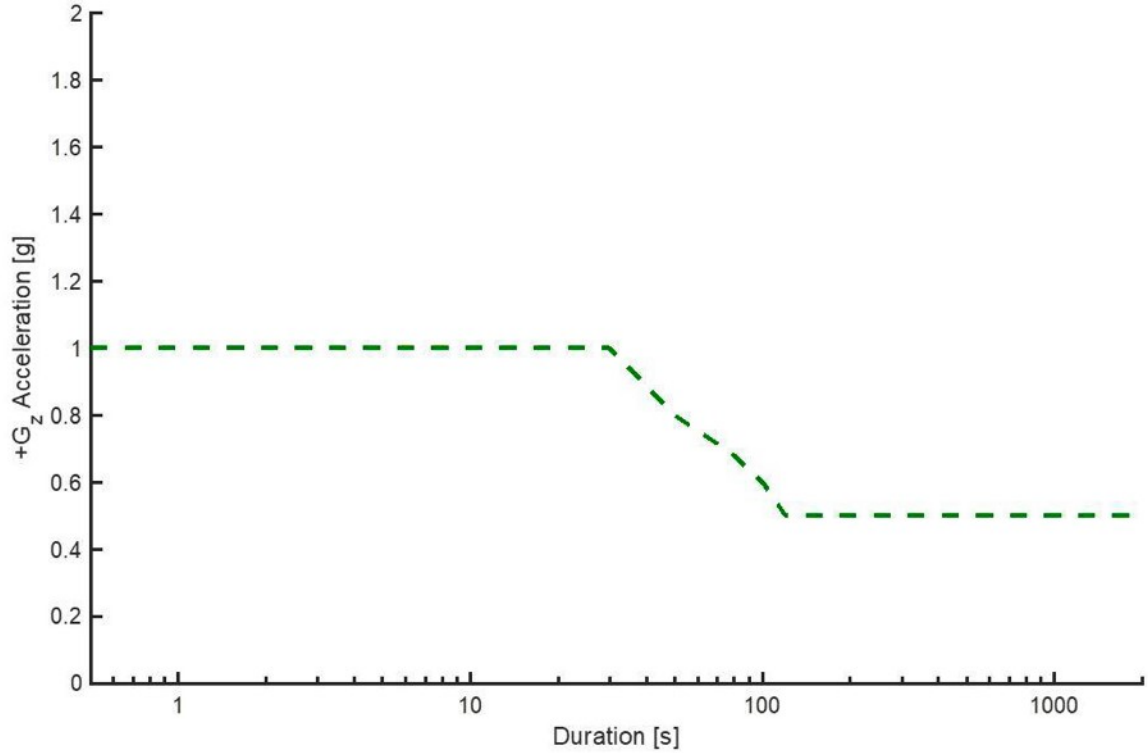
Duration (sec)	0.5	100	Sustained
Acceleration (g)	2	1	1

Figure 4: ±GY Linear Sustained Acceleration Limits



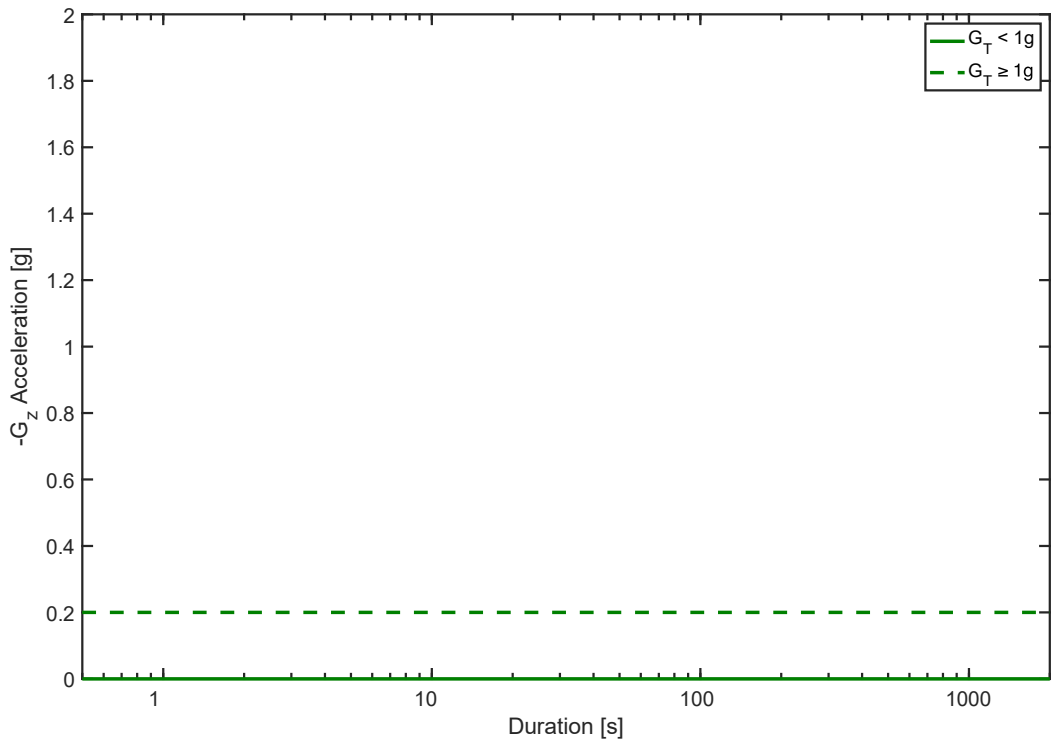
Duration (sec)	0.5	30	540	Sustained
Acceleration (g)	1	1	0.16	0.16

Figure 5:+GZ Linear Sustained Accelerations Limits (Standing, Short Duration)



Duration (sec)	0.5	30	50	80	100	120	Sustained
Acceleration (g)	1	1	0.8	0.68	0.6	0.5	0.5

Figure 6:+GZ Linear Sustained Acceleration Limits (Seated or Standing with Countermeasure, Long Duration)



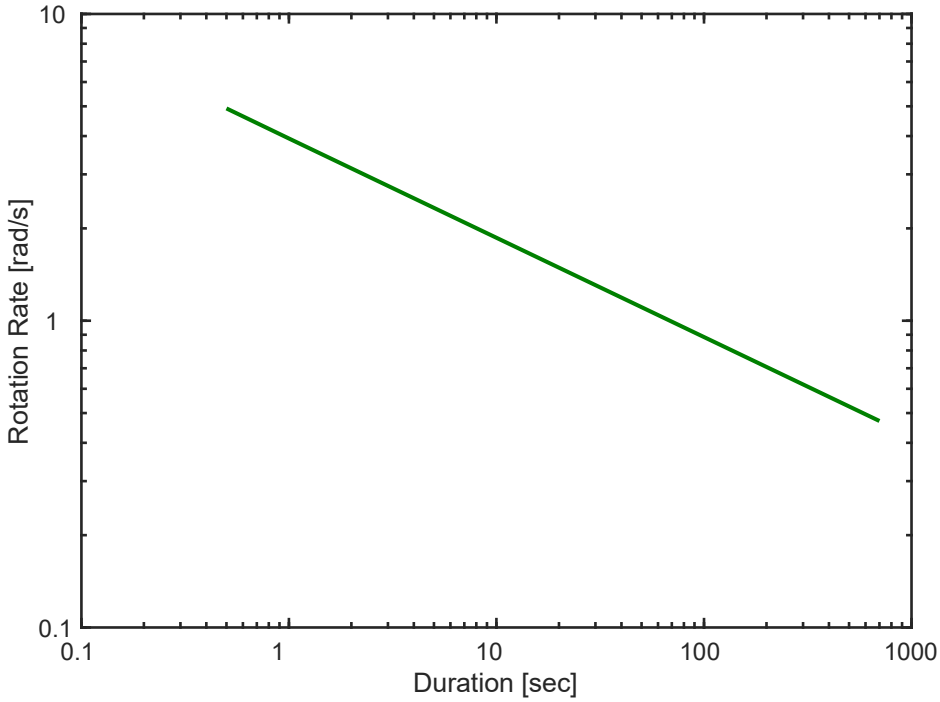
Duration (sec)	0.5	Sustained
Acceleration (g) ($G_T \geq 1$)	0.2	0.2
Acceleration (g) ($G_T < 1$)	0	0

Figure 7: -GZ Linear Sustained Acceleration Limits

HLS-HMTA-0060 Rotational Velocity

The system shall limit crew exposure to rotational velocities in yaw, pitch, and roll by staying below the limits specified in Figure 8, Rotational Velocity Limits.

Rationale: The limits in this figure represent safe levels of sustained rotational velocities 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.



Duration (sec)	0.5	1	700
Rotational Rate (rad/sec)	5	4	0.5

Figure 8. Rotational Velocity Limits.

HLS-HMTA-0061 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/s2.

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/s2 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.

HLS-HMTA-0062 Transient Translational Acceleration

The system shall limit the magnitude, direction, and duration of crew exposure to transient translational acceleration (≤0.5 seconds) by limiting the injury risk criterion (β) to less than 1.0 (Low) with sufficient restraint as described in NASA/TM- 2013-217380REV1, Application of the Brinkley Dynamic Response Criterion to Spacecraft Transient Dynamic Events. The dynamic response (DR) limit values in the document are only applicable for seated crew meeting the constraints specified. For standing crew, the DR limits specified in Table 14: Dynamic Response Limits for crew in a standing posture shall be used with proper restraint and/or support.

Rationale: The Brinkley Dynamic Response model will provide an injury risk assessment during dynamic phases of flight for accelerations <0.5 seconds. Application of this model assumes that the design meets the constraints set forth in NASA/TM- 2013-217380REV1, Application of the Brinkley Dynamic Response Criterion to Spacecraft Transient Dynamic Events. 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 spaceflight transient accelerations 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 give the Brinkley model the highest fidelity in the Gz axis. Although the maximum allowable Brinkley β-value should be 1.0 for any given level of risk, the vehicle's 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 DR 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 any accelerations lasting less than 0.5 seconds. Application of the Brinkley Dynamic Response model for required design criteria is described in NASA/TM- 2013-217380REV1, Application of the Brinkley Dynamic Response Criterion to Spacecraft Transient Dynamic Events, including required design criteria necessary to meet the ground rules for application of the model. Note that –Gz accelerations are not allowed, as it would pull the crewmember away from the floor. Structural failure of the vehicle may present an occupant protection hazard through impingement on 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 spaceflight 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 +GZ 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 Table 14 are only valid If the restraint configuration prevents the crewmember from losing balance during the dynamic event. The +Gz standing limits were developed by a panel of experts and were based on a review of Apollo lunar landing impact data, Space Shuttle and International Space Station post-flight crew jump data, and ISS inflight treadmill foot strike data. In addition, data from vertical loading of the foot-ankle-tibia (Pintar, 2016) and ankle (Kuppa, 2001) were included. To develop the ±Gx and ±Gy limits, the ratio (6.5) between the seated and standing +Gz dynamic response limits was used to scale the off-axis limits.

Table 15: Dynamic Response Limits for crew in a standing posture shall be used with proper restraint

Reduced Gravity duration prior to dynamic loads	$+G_x$	$-G_x$	$\pm G_y$	$+G_z$	$-G_z$
≤30 days	5.4	-4.3	±2.3	2.7	0
>30 days	5.4	-4.3	±1.7	2.0	0

HLS-HMTA-0415 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.

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.

HLS-HMTA-0063 Acceleration Rate of Change

The system shall limit crew exposure to acceleration rates of change no larger than 500 g/s during any sustained (>0.5 second) acceleration event.

Rationale: Acceleration onset rates greater than 500 g/s significantly increase the risk of incapacitation, thereby threatening crew survival.

HLS-HMTA-0065 Vehicle Acceleration Monitoring and Analysis

The system shall collect vehicle and crew acceleration parameters and specific kinematic responses during all dynamic phases of flight (e.g. ascent, abort, descent and landing) to correlate with any injuries incurred by the crew.

Rationale: Systems are to be capable of monitoring the vehicle and crew specific acceleration levels and associated crew kinematic responses (e.g. video) during dynamic phases of flight in order to correlate with any crew 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 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.

HLS-HMTA-0066 Hang Time Limit

The system shall limit crew exposure to suspension trauma conditions to 7 minutes or less.

Rationale: 7 minutes was chosen as the hang time tolerance limit to protect the crew from a variety of illnesses and post-landing complications. This time limit reduces the probability the crew will experience suspension trauma symptoms. Suspension trauma, or harness hang trauma, is the closest comparable condition to the crew hanging position. Space Flight Medicine research showed that cognitive deficits could occur within 3.5 minutes for a deconditioned crew, affecting their ability to take action if required. They also concluded that uprighting should be complete within 7 minutes to prevent sudden increases 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.

HLS-HMTA-0067 Acoustic Limits

The System should limit crew exposure to acoustic noise and protect for alarm audibility and crew communication.

Rationale: An acceptable acoustic environment is desirable 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 NASA-STD-3001 Rev B. Table 17, Acoustic Limits for Ascent, Landing, and Abort Phases, and Table 18, Acoustic Limits for Lunar Surface Phase, are summaries of the acoustic requirements listed in the following sections, referenced by requirement number.*

Table 16: Acoustic Limits for Ascent, Landing, and Abort Phases

Mission Phase	24-Hour Exposure	Ceiling	Impulse Noise	Infrasonic Noise 1-20 Hz
Ascent	**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***
Descent	**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***
Abort	**Noise dose ≤100, equivalent to 8-hour 85 dBA TWA**	**≤115 dBA**	**≤140 dB peak SPL**	**< 150 dB***
Personal Communication	**Noise dose ≤100, equivalent to 8-hour 85 dBA TWA**	**≤115 dBA**	**≤140 dB peak SPL**	**Not Applicable**

***Hearing protection CANNOT be used to satisfy this limit.**

Table 17: Acoustic Limits for Lunar Surface Phase*

On-Orbit	**NC-50 Octave Band SPL limits. See Figure and Table in Continuous Noise Limits.**	**<85 dBA**	**Specified Sound Level (dBA) depending on duration, reference Table Acoustic Limits for Accent, Descent, and Abort Phases**	**≤140 dB peak SPL**
a. For Sleep on Missions > 30 days	**NC-40 Octave Band SPL limits. See Figure and Table in Continuous Noise Limits.**	**<85 dBA**	**+10 dBA or less above background**	**+10 dB peak or less above background**
b. For Sleep on Missions ≤ 30 days	**NC-50 Octave Band SPL limits. See Figure and Table in Continuous Noise Limits.**	**<85 dBA**	**+10 dBA or less above background**	**+10 dB peak or less above background**

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

HLS-HMTA-0068 Intermittent Noise Limits

For hardware items generating intermittent noise that operate for 8 hours or less, the maximum noise emissions measured 0.6 m from the loudest hardware surface shall be determined according to Table 19, Intermittent Noise A-Weighted SPL and Corresponding Operational Duration Limits for any 24-hour Period (ref NASA-STD-3001 Vol 2, Rev B). Both impulse and cabin depressurization valve noise are excluded from this requirement. Neither hearing protection nor communications headsets may be used to satisfy this requirement.
This requirement relaxes the continuous noise limits in HLS-HMTA-0076

Rationale: Table 19 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. Refer to Acoustic Limits for Lunar Surface Phase.

Table 18: 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

HLS-HMTA-0069 Cabin Depressurization Valve Hazardous Noise Limit

The system shall limit the maximum A-weighted overall SPL, at the crewmember's ear, to 105 dBA or less during cabin depressurization valve operations. The noise attenuation effectiveness of hearing protection, communications headsets, and/or helmets may be used to satisfy this requirement.

Rationale: Noise levels above 115 dBA have been shown to produce noise-induced hearing loss, and the 105-dBA limit allows headroom for alarms and voice communications. Historically, cabin depressurization valves have produced a high level of noise. Whether or not the use of hearing protection may be used to satisfy this requirement will be specified in the Level III documentation. This limit does not apply to impulse noise. The Cabin Depressurization Valve will be a significant intermittent noise contributor, and the crew must be protected from excessive noise that may cause temporary or permanent hearing damage. Without this relaxed requirement, depressurization valves would be expected to meet the intermittent noise requirement (HLS-HMTA-0068).

HLS-HMTA-0070 Cabin Depressurization Valve Noise Dose Limits

The system shall limit the noise dose at the crewmember's ear, calculated over any 24-hour period, to 100% or less, where the 24-hour noise dose, D, is calculated by:

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

where N is the number of noise exposure events during the 24-hour period, Cn is the actual duration of the exposure event, and Tn is the maximum noise exposure duration allowed, based on the specific noise level, Ln, of an exposure event, calculated using:

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

during cabin depressurization valve operations.

Rationale: 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 of Occupational Safety and Health (NIOSH), using the 3-dB trading rule. This limit does not apply to impulse noise. Whether or not the use of hearing protection may be used to satisfy this requirement will be specified in the Level III documentation. Without this relaxed requirement, depressurization valves would be expected to meet the intermittent noise requirement (HLS-HMTA-0068).

HLS-HMTA-0071 Ascent, Landing and Abort Noise Exposure Limits

During ascent, landing, abort operations and other lander burns, 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:

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

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:

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

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. Contractor approach 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 requirement. Refer to Table 17 Acoustic Limits for Ascent, Landing, and Abort Phases.

HLS-HMTA-0072 Sound Level Ceiling Limit for Ascent and Landing

During ascent, landing and other lander burn 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; the noise attenuation effectiveness of hearing protection or communications headsets may be used to satisfy this requirement.

Rationale: Noise levels above 115 dBA have been shown to produce noise-induced hearing loss. In cases where audio communications are required, e.g., ascent, landing, a 105-dBA limit is recommended to allow 10 dB of headroom for alarms and voice communications. Any planned use of hearing protection to satisfy this requirement is to be well documented and approved. Contractor approach to meet this requirement is to be included in the Acoustic Noise Control Plan. Refer to Table 17 Acoustic Limits for Ascent, Descent, and Abort Phases.

HLS-HMTA-0073 Sound Level Ceiling Limit for Aborts

During 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; the noise attenuation effectiveness of hearing protection or communications headsets may be used to satisfy this requirement. *Refer to Table 17 Acoustic Limits for Accent, Landing, and Abort Phases.*

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. Any planned use of hearing protection to satisfy this requirement is to be well documented and approved. Refer to Table Acoustic Limits for Ascent, Descent, and Abort Phases.

HLS-HMTA-0074 Ascent, Landing, Abort and Other Burn Impulse Noise Limits

During ascent, landing, abort other lander burn operations, impulse noise measured at the crewmember's ear location shall be limited to less than 140-dB peak SPL; the noise attenuation effectiveness of hearing protection or communications headsets may be used to satisfy this requirement. Impulse sound is a change in SPL of more than 10.0 dB in one second or less.

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). Any planned use of hearing protection to satisfy this requirement is to be well documented and approved. Contractor approach to meet this requirement is to be included in the Acoustic Noise Control Plan. Refer to Table 17 Acoustic Limits for Ascent, Landing, and Abort Phases.

HLS-HMTA-0075 Hazardous Noise Limits for All Phases Except Ascent, Landing, Aborts and Other Lander Burns

For off-nominal operations, broadcast communications, and maintenance activities, the A-weighted sound level (excluding impulse noise and alarm signals) shall be less than 85 dBA, regardless of time duration. 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 ascent, descent 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 environment is safe. This is not intended for nominal hardware emissions but to limit the sound level of sources such as communications systems and levels that occur during planned off-nominal operations and maintenance activities. Nominal on-orbit acoustic levels are limited by the Continuous and Intermittent Noise requirements HLS-HMTA-0076 and HLS-HMTA-0068. Refer to Acoustic Limits for Lunar Surface Phase.

HLS-HMTA-0076 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 8a, NC Curves, and Table 20, Octave Band SPL Limits for Continuous Noise, dB re 20 μPa; the noise attenuation effectiveness of hearing protection or communications headsets may not be used to satisfy this requirement.

Rationale: NC-50 limits noise levels within the crew-habitable volume to allow adequate voice communications and habitability during mission operations. The noise limit at 16 kHz does not appear in Figure 8a but is given in Table 20. SPLs for continuous noise do not apply to alarms, communications, or noise experienced during maintenance activities. Refer to Acoustic Limits for Lunar Surface Phase.

Table 19: Octave Band SPL Limits for Continuous Noise

	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

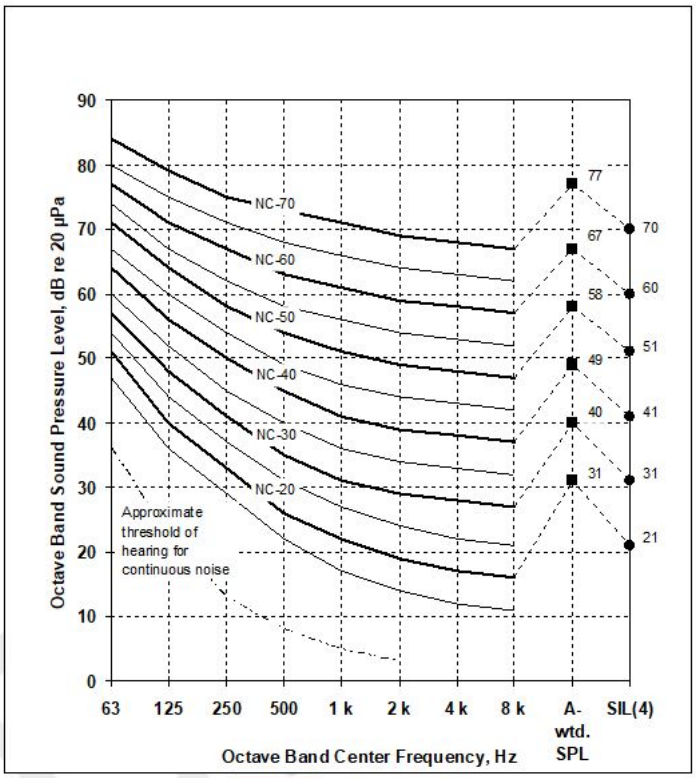


Figure 8—NC Curves

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

Figure 8a: NC Curves

HLS-HMTA-0077 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.

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.

HLS-HMTA-0078 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. The noise attenuation effectiveness of hearing protection may not 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. Refer to Acoustic Limits for Lunar Surface Phase.

HLS-HMTA-0079 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 ascent and landing. The noise attenuation effectiveness of hearing protection or communications headsets may not be used to satisfy this requirement. Impulse sound is a change in SPL of more than 10.0 dB in one second or less.

Rationale: A limit of 140-dB peak SPL for impulse noise prevents acoustic trauma (MIL-STD-1474, current version). Refer to Acoustic Limits for Lunar Surface Phase.

HLS-HMTA-0080 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.

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.

HLS-HMTA-0081 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; the noise attenuation effectiveness of hearing protection or communications headsets may not 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.) Refer to Table 17 Acoustic Limits for Ascent, Landing, and Abort Phases.

HLS-HMTA-0082 Noise Limit for Personal Communication Devices

The system shall limit the maximum A-weighted sound level at the crewmember's ear created by a personal communication 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 communication devices are allowed to be at higher levels to overcome the noise generated during ascent and landing. A personal communication device may be an integrated part of the EVA helmet or an independent communication headset. 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 HLS-HMTA-0071. Refer to Table 17 Acoustic Limits for Ascent, Landing, and Abort Phases.

HLS-HMTA-0083 Vibration Limits

The system should limit crew exposure to environmentally induced vibrations.

Rationale: Certain health risks and performance degradation can be attributed to exposure to environmentally induced vibration in spaceflight. The vibration levels that reach the crew are the result of several factors provided by the system, including connecting structure, means of vibration attenuation, etc. Limits ensure that vibration to the crew does not cause injury during periods of acceleration and rotational velocity and does not negatively impact crew habitability during sustained, high or low-level vibration exposure. For long-duration exposure (~8.5 hours), smaller vibrations to which the crew is exposed can adversely affect crew sleep; while mission tasks and associated equipment should be designed to avoid unacceptable performance degradation during periods of vibration.

HLS-HMTA-0084 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 21, Frequency-Weighted Vibration Limits by Exposure Time during Dynamic Phases of Flight (ref NASA-STD-3001 Vol 2, Rev B).

Rationale: 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 lunar descent and ascent. If the dynamic event exceeds this 10-minute duration, requirement [HLS-HMTA-0085] "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 shall be based on a running 1-second time window.

Table 20: Frequency-Weighted Vibration Limits by Exposure Time during Dynamic Phases of Flight

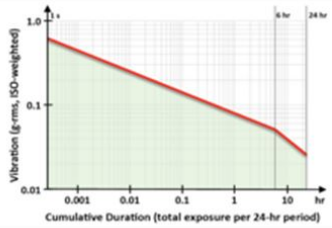
Maximum Vibration Exposure Duration per 24-hr Period	Maximum Frequency-Weighted Acceleration
10 min	3.9 m/s^2 RMS (0.4 g RMS)
1 min	5.9 m/s^2 RMS (0.6 g RMS)

HLS-HMTA-0085 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.

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." This is depicted in Table 22.

Table 21: 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 between 0.5 and 80 Hz, accumulated over any continuous 24-hr duration, calculated in 1-second intervals, and weighted in accordance with ISO 2631-1:1997(E), does not exceed the minimum health guidance caution zone level defined in Figure XX (below), Frequency-Weighted Vibration Limits by Exposure Time During Non-Sleep Phases of Mission.	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." Following MIL-STD-1472G, the zone is bounded at lower durations by ISO 2631-1:1997(E), Eq. B.5, $eVDV = 8.5 = 1.4\ a_w T^{0.25}$ where eVDV is the Equivalent Vibration Dosage Value, T is time in seconds and, a_w is the computed frequency-weighted acceleration. For higher durations, the zone is bounded by $a_w T^{0.5} = a_{w24} T_{24}^{0.5}$ from ISO 2631-1:1997(E), Eq. B.1, where a_{w24}= 0.25 m/s^2 at T_{24} = 795600 seconds (i.e., 24 hours) as shown in ISO 2631-1:1997(E), Figure B.1. The transition between the two duration equations occurs at T = 5.96 hours at which the weighted acceleration, a_w = 0.502 m/s2.

HLS-HMTA-0086 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 20283-5:2016(E), 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 2-minute interval during the crew sleep period.

Rationale: For long-duration exposure (~8 hours), smaller magnitude vibration exposure can adversely affect crew sleep.

HLS-HMTA-0087 Vibration Limits for Performance

Crew task performance (e.g., motor control accuracy and precision, vision/readability, speech clarity, attentional focus) shall not be degraded by vibration.

Rationale: Tasks and associated equipment should be designed to avoid unacceptable performance degradation during periods of vibration. Thus, while vibration limits may depend on the specific task, specific tasks may be selected or designed to accommodate the associated vibration level. Performance criteria need to be established for tasks and then an assessment made for the impact of vibration on performance. The level and fidelity of assessment will depend on the criticality of the task.

HLS-HMTA-0088 Radiation protection, limitations and monitoring

The system should protect, limit and monitor crew exposure to radiation.

Rationale: Crew occupational exposure to ionizing radiation 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 age- and gender-dependent career cancer risks 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.

HLS-HMTA-0089 Crew Radiation Exposure Limits

The program 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.

HLS-HMTA-0090 Ionizing Radiation Alerting

The system shall include a method to alert all crewmembers 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 MCC 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 needs to be given sufficient time to prepare for a high radiation event.

HLS-HMTA-0091 Natural Sunlight Exposure Limits

Windows shall limit sunlight exposure to the crew from spectral radiance or irradiance as applicable within wavelengths between 180 nm to 3000 nm per methodology and limits given in the 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 later).

Rationale: This requirement is intended to prevent ocular injury from sunlight exposure with wavelengths between 180 and 3000 nm. Any exposure must consider the entire window configuration of the incident radiation prior to its interaction with a crewmember's body including any concentration, diffusion, or filtering. Protection from NIR may be accomplished through the reduction of effective irradiance or by limiting exposure times. The transmittance required for windows, visors, and other optical devices can be reconciled with protection from NIR through the use of temporary filters, proper material selection, apertures, or other appropriate means. The sun subtends an angle of approximately 9 milliradians when observed from earth and is therefore considered a small source.

HLS-HMTA-0092 Artificial Light Exposure Limits for Visible sources below 10,000 nits

The system shall not expose the crew to an artificial light source unless the light source emits only in the visible spectrum and does not exceed an average luminance of 10,000 nits (1 nit = 1 Candela per meter squared).

Rationale: This requirement is intended to prevent ocular injury caused by overexposure to visible radiation. The value of 10,000 Nits (Candela per Meter Squared) is commonly utilized specifications in commercial hardware and is established based on guidance from ACGIH 2014. Examples of artificial light sources include LEDs, illumination lamps and display screens.

HLS-HMTA-0093 Artificial Light Exposure Limits for Visible sources above 10,000 nits and Infrared (IR) Sources

The system shall limit crew exposure to below the TLV as calculated per ACGIH TLVs version 2014 or later, for visible light sources whose emission is only in the visible spectrum and whose luminance exceeds 10,000 nits; and artificial light sources that include emissions in the infrared (IR) spectrum, including LEDs and illumination lamps.

Rationale: Visible sources that exceed 10,000 nits and infrared or near-infrared sources must determine the TLV per ACGIH-2014 or newer. The information in

ACGIH allows for the qualification of the relationship between source strength and acceptable exposure times, or exposure rate dependence, for each potential injury pathways: Photochemical injury to the retina from chronic blue-light exposure [305 nm: 700 nm], thermal injury to the cornea and lens from infrared light exposure [770 nm: 3000 nm], thermal Injury to the retina from near-infrared light exposure [770 nm: 1400 nm], and thermal injury to the retina from visible light exposure [380 nm: 1400 nm].

HLS-HMTA-0094 Artificial Light Exposure Limits for Ultraviolet (UV) Sources

The system shall fully contain artificial ultraviolet sources in order to prevent crew exposure.

Rationale: This requirement is intended to prevent ocular injury and skin damage caused by overexposure to ultraviolet radiation. Acceptable methods of containment included the use of light-tight structures and enclosures to fully contain the UV at the source, or UV optical light obstruction by other means (e.g. screens, shields, filters) before reaching the crew to prevent exposure.

HLS-HMTA-0095 RF Non-Ionizing Radiation Exposure Limits

The system shall limit the crew exposure to radio-frequency (RF) electromagnetic fields to the limits specified in the modified IEEE C95.1-2005 standard (lower tier).

Rationale: All devices that generate radio frequency radiation (including, but not limited to, antennas and wireless systems) must limit the amount of this radiation to which the crew can be exposed. These limits are modified from the Institute of Electrical and Electronic Engineers (IEEE) C95.1-2005, "Standard Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz." 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 corps and resulted in the relaxation of the C95.1-2005 limits as per Figure 3 "Occupational Exposure Limits for Radio-Frequency Electromagnetic Fields".

HLS-HMTA-0096 Laser Exposure Limits

The system shall maintain ocular and dermal exposure of the crew to laser systems 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 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 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.

HLS-HMTA-0097 Solar Particle Event (SPE) protection

The HLS shall limit crew radiation exposure due to Solar Particle Events using the ALARA principle.

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 Solar Particle Events is ALARA when the expenditure of further resources would be unwarranted by the reduction in exposure that would be achieved. The goal would be for the system to provide protection to ensure that gray equivalent to astronaut blood forming organs (BFOs) does not exceed 250 mGy-Eq. for the design Solar Particle Event (SPE), specified in Table 23, Design Reference SPE Environment Proton Energy Spectrum.

Table 22: Design reference SPE Environment Proton Energy Spectrum

Energy (MeV)	Proton Fluence (#/cm^2-MeV)	Energy (MeV)	Proton Fluence (#/cm^2-MeV)	Energy (MeV)	Proton Fluence (#/cm^2-MeV)	Energy (MeV)	Proton Fluence (#/cm^2-MeV)	Energy (MeV)	Proton Fluence (#/cm^2-MeV)
1.000E-02	7.761E+14	5.770E-01	3.651E+11	4.810E+00	9.004E+09	3.426E+01	1.641E+08	2.484E+02	5.714E+05
1.338E-02	4.329E+14	6.480E-01	2.979E+11	5.317E+00	7.510E+09	3.775E+01	1.298E+08	2.756E+02	4.006E+05
1.790E-02	2.424E+14	7.263E-01	2.442E+11	5.875E+00	6.257E+09	4.160E+01	1.022E+08	3.060E+02	2.773E+05
2.391E-02	1.369E+14	8.129E-01	2.008E+11	6.490E+00	5.208E+09	4.584E+01	8.008E+07	3.407E+02	1.862E+05
3.183E-02	7.805E+13	9.086E-01	1.655E+11	7.168E+00	4.330E+09	5.052E+01	6.136E+07	3.794E+02	1.230E+05
4.210E-02	4.531E+13	1.014E+00	1.368E+11	7.914E+00	3.594E+09	5.568E+01	4.700E+07	4.232E+02	8.060E+04
5.511E-02	2.697E+13	1.130E+00	1.135E+11	8.736E+00	2.979E+09	6.137E+01	3.600E+07	4.728E+02	5.236E+04
7.112E-02	1.657E+13	1.258E+00	9.421E+10	9.641E+00	2.465E+09	6.765E+01	2.754E+07	5.291E+02	3.367E+04
9.027E-02	1.055E+13	1.400E+00	7.839E+10	1.064E+01	2.035E+09	7.460E+01	2.103E+07	5.930E+02	2.141E+04
1.125E-01	6.989E+12	1.556E+00	6.527E+10	1.174E+01	1.677E+09	8.226E+01	1.603E+07	6.665E+02	1.337E+04
1.375E-01	4.810E+12	1.729E+00	5.441E+10	1.294E+01	1.379E+09	9.074E+01	1.219E+07	7.505E+02	8.141E+03
1.657E-01	3.411E+12	1.919E+00	4.541E+10	1.427E+01	1.131E+09	1.001E+02	9.237E+06	8.471E+02	4.859E+03
1.968E-01	2.489E+12	2.129E+00	3.792E+10	1.574E+01	9.248E+08	1.105E+02	6.966E+06	9.588E+02	2.856E+03
2.303E-01	1.872E+12	2.361E+00	3.168E+10	1.735E+01	7.542E+08	1.220E+02	5.234E+06	1.091E+03	1.633E+03
2.675E-01	1.428E+12	2.617E+00	2.647E+10	1.913E+01	6.132E+08	1.348E+02	3.908E+06	1.244E+03	9.199E+02
3.082E-01	1.108E+12	2.900E+00	2.213E+10	2.108E+01	4.969E+08	1.490E+02	2.902E+06	1.418E+03	5.152E+02
3.525E-01	8.711E+11	3.211E+00	1.850E+10	2.323E+01	4.013E+08	1.648E+02	2.134E+06	1.625E+03	2.802E+02
4.010E-01	6.929E+11	3.555E+00	1.546E+10	2.561E+01	3.229E+08	1.824E+02	1.560E+06	1.869E+03	1.486E+02
4.542E-01	5.560E+11	3.933E+00	1.292E+10	2.822E+01	2.588E+08	2.018E+02	1.131E+06	2.158E+03	7.696E+01
5.126E-01	4.493E+11	4.350E+00	1.079E+10	3.109E+01	2.065E+08	2.239E+02	8.074E+05	2.500E+03	3.891E+01

HLS-HMTA-0098 Nutrition Stowage Care

The system shall accommodate stowage for crew nutrition per GFE List and IRD/ICD.

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. While NASA will be providing the food, the provider must accommodate the food in a manner that makes it available for use in a non-degraded condition.

HLS-HMTA-0099 Food Preparation

The system shall provide the accommodations 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 and a method to rehydrate. Stowage is needed for the food, as well as all the implements for preparation and consumption.

HLS-HMTA-0100 Food Preparation and Cleanup

The food system shall allow the crew to unstow supplies, prepare meals, and clean up for all crewmembers.

Rationale: Meal preparation and cleanup activity planning takes into account previous spaceflight lessons learned, the water delivery system, stowage configuration. Consideration of mission timeline should factor into task analysis of this activity. This is to help ensure that mission goals, objectives, and timelines are not negatively impacted.

HLS-HMTA-0101 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.

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. Spaceflight lessons learned indicate this has been an issue during Apollo and ISS missions.

HLS-HMTA-0102 Food and Beverage Heating

The system should provide the capability to heat food and beverages to a temperature appropriate for the given item.

Rationale: For the 2024 mission up to 7.5 days, hot food and drinks are not required. 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 and supports adequate consumption of the food provided. The vehicle is to provide the ability to heat dehydrated and non-rehydrated foods.

HLS-HMTA-0103 Food Spill Control

The system should provide the ability to control 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.

HLS-HMTA-0104 Food System Cleaning and Sanitizing

The system should 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.

HLS-HMTA-0105 Personal Hygiene Capability

The system shall provide the accommodations for oral hygiene, personal grooming, and body cleansing.

Rationale: Oral hygiene, personal grooming, and body cleansing activities are to be accommodated by the system through provision of adequate and comfortable facilities since these activities are required to maintain personal cleanliness. Cleanliness is required to prevent disease and odor, and also maintains crew comfort and productivity.

HLS-HMTA-0106 Crew Task Volume

The system shall provide a habitable volume that accommodates crew living and work tasks.

Rationale: To maintain a habitable volume and high level of mission performance and safety, it is important that the architecture of the vehicle is designed to provide defined locations and operating task volumes that enable expected crew activities, including mission operations, habitability functions, and translation (for example, movement between areas). Required volume is a function of the number of crewmembers, number of mission and contingency days, and crew operations/tasks (both nominal and off-nominal). Adequate internal size, in terms of volume and surface area, needs to be provided to ensure expected number of crewmembers can safely, efficiently, and effectively perform individual and group mission tasks and recreational activities, including, but not limited to, work, sleep, dining together, personal hygiene, private crew areas, translation, egress, ingress, pressurized suit donning/doffing, emergency medical treatment, and other tasks necessary for a safe and successful mission as determined by a task analysis. It is important to consider all types of volume– pressurized, habitable, and net habitable, in accordance with JSC/SA/Chief Medical Officer in Memo SA-16-156, when determining the amount of volume that is necessary.

Mission and volume designers are to carefully analyze crew tasks in order to determine volume needs of the crew, crew equipment, storage, trash containment volumes and trash transition plans to ensure they are adequately sized to provide adequate habitable volume for the crew to effectively and efficiently perform mission objectives. Generally, the most efficient layout is to place functions adjacent to each other when they are used sequentially or in close coordination. For example, food stowage and food preparation areas shall be located near one another to minimize the time required to retrieve food for meals and promote group dining for behavioral health benefits; and consistent spatial orientation and visual distinctions such as identifiers and aids can promote effective execution of mission tasking. There are some limitations to this general rule, however. Co-location of unrelated activities can degrade operations, resulting in increased workload and operational delays, and efforts 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, and odor. Furthermore, traffic flow shall not interfere with other unrelated operational and recreational activities of the crew. These activities may include sensitive spacecraft control, routine servicing, experimentation, eating, sleep, and relaxation.

HLS-HMTA-0107 Dining Accommodations

The system should allow the crew to prepare each meal for two crewmembers within a single 30-minute period.

Rationale: If applicable, the water delivery and food heating systems must support meal preparation for the full crew, if the mission schedule requires that they eat meals together. The food system should account for the volume for all the crew to prepare their meal, gather simultaneously, and accommodate any equipment needed to

restrain the food and implements, including utensils necessary for dining. This 30-minute period is based on a 1-hour timelined meal. 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.

HLS-HMTA-0108 Body Cleansing Privacy

The system should provide for privacy during body cleansing.

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.

HLS-HMTA-0109 Personal Hygiene Provision

Stowage space for personal hygiene items shall be provided for each crewmember.

Rationale: Each crewmember is to have personal hygiene provisions, e.g., tooth brush, tooth paste, deodorant for body cleansing, 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 the microgravity environment.

HLS-HMTA-0111 Body Waste Management Capability

The system shall provide accommodations 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. This is provided as GFE, but the vehicle will need to provide a location for the system and associated consumables.

HLS-HMTA-0112 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.

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. Spaceflight lessons learned indicate this has been an issue during Apollo and ISS missions.

HLS-HMTA-0113 Body Waste Management Privacy

The system should 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 waste management system.

HLS-HMTA-0114 Body Waste Management Provision

Body waste management supplies shall be accessible to and within reach of crewmembers using the waste management system.

Rationale: Personal hygiene and body waste management supplies such as tissues and towels need to be accessible by crew confined to the WMS equipment vicinity.

HLS-HMTA-0115 Body Waste Odor

The system shall provide odor control for the waste management system.

Rationale: Uncontrolled waste-associated odors can have an adverse effect on crew performance

HLS-HMTA-0116 Body Waste Trash Receptacle Accessibility

Body waste management trash collection shall be accessible to and within reach of crewmembers using the 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 locations 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.

HLS-HMTA-0117 Private Body Inspection Accommodation

The body waste management system shall provide a means and sufficient volume for crewmembers to perform private bodily self-inspection and cleaning after urination and defecation.

Rationale: In microgravity, body waste can float and in partial gravity there can be increased splashback as compared to terrestrial gravity; therefore, after waste management, it is important for crewmembers to verify that they are clean.

HLS-HMTA-0118 Body Waste Management System Cleanliness

All body waste management facilities and equipment shall be capable of being cleaned and sanitized.

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. The waste management system will be provided as GFE, but the vehicle location it is placed in needs to be able to be easily cleaned and sanitized. 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.

HLS-HMTA-0119 Medical Capability

The system shall provide both pharmaceutical and medical supplies to support both nominal and contingent medical conditions defined in TBS NASA-controlled document.

Rationale: These supplies must be capable of being utilized by all crewmembers. These medical capabilities will be required to protect crew health and respond to medical contingencies. The capabilities required to be provided will be defined by NASA flight surgeons in the above NASA document.

HLS-HMTA-0120 Biological Waste Containment and Disposal

Biological hazards, like blood and other bodily fluids, shall be contained and safely disposed to minimize contamination of other crewmembers.

Rationale: If not properly contained, contents could damage equipment, injure crewmembers, and transmit disease. Biological waste, including suited feces/urine collection devices, vomit, and feminine hygiene products, can also cause injury and transmit disease.

HLS-HMTA-0121 Medical Treatment Restraints

The capability should 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. 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.

HLS-HMTA-0122 Medical Sharps Disposal

The system shall accommodate the safe disposal of sharp items (e.g. syringe needles) to prevent inadvertent injury to other crewmembers.

Rationale: The system will provide an accessible stowage volume close to where medical screening, diagnosis, and treatment is performed to accommodate the safe disposal of sharp items.

HLS-HMTA-0123 Deceased Crew

The system shall accommodate the handling of deceased crew members.

Rationale: The system will provide an accessible volume to stow necessary supplies and hardware required to handle deceased crew members.

HLS-HMTA-0124 Stowage Provisions

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.

HLS-HMTA-0125 Personal Stowage

The system should 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.

HLS-HMTA-0126 Stowage Location

All relocatable items, e.g., food, EVA suits, and spare parts, should 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.

HLS-HMTA-0127 Stowage Interference

The system should 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.

HLS-HMTA-0128 Stowage Restraints

The system shall provide the capability to restrain relocatable items during microgravity, transient accelerations, and vibrations.

Rationale: Stowed items are to be restrained so that they are not free to move during vehicle motion, under the influence of internal air movement, or after inadvertent contact. These restraints assist in keeping the crew safe from items moving about and also assist in ensuring that stowed items remain where required during operations and crew tasks.

HLS-HMTA-0129 Priority of Stowage Accessibility

Stowage items should 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.

HLS-HMTA-0130 Stowage Operation without Tools

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.

HLS-HMTA-0131 Stowage Access while Suited

Stowed items to be used when crewmembers are suited shall be accessible by a suited crewmember.

Rationale: Stowage items need features that allow suited crew to access, open, close, or manipulate the items. This applies to normal as well as contingency operations.

HLS-HMTA-0132 Inventory Tracking

The system should 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 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.

HLS-HMTA-0133 Identification System

The stowage identification system should 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.

HLS-HMTA-0134 Inventory Operations

The system should 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 spaceflight have indicated that past inventory operations have exceeded the allocated time required to accomplish the tasks. This can interfere with other expected tasks.

HLS-HMTA-0135 Nomenclature Consistency

The nomenclature used to refer to the items tracked by the inventory management system should be consistent with procedures and labels.

Rationale: It is imperative that spaceflight 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.

HLS-HMTA-0136 Unique Item Identification

Items that need to be uniquely identified should 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.

HLS-HMTA-0137 Interchangeable Item Nomenclature

Items within the inventory management system that are identical and interchangeable should 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.

HLS-HMTA-0138 Trash Accommodation

The system shall provide a trash management system to accommodate (stow, neutralize, and dispose) all expected wet and dry trash, including sharp items, harmful chemicals, and biological and radioactive waste.

Rationale: If not properly contained, trash contents could damage equipment, injure crewmembers, and transmit disease. Different types of trash require specific types of wrapping and containment. The trash management plan identifies the types of trash to be generated during mission operations; such identification then guides the disposition of the trash. Flight crews as well as ground personnel are expected to manage trash.

HLS-HMTA-0139 Trash Volume Allocation

Trash stowage volumes shall be defined and 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. Dedicated trash stowage volumes and locations are needed and are to be coupled with appropriate packaging and containment.

HLS-HMTA-0140 Trash Stowage Interference

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.

HLS-HMTA-0141 Trash Odor Control

The trash management system shall provide odor control of trash.

Rationale: Uncontrolled odors can have an adverse effect on crew performance and can exacerbate pre-existing symptoms of SAS.

HLS-HMTA-0142 Trash Contamination Control

The trash management system shall prevent the release of trash into the habitable environment.

Rationale: Many components of trash act as nutrient sources for microorganisms that can quickly increase their concentrations. These microorganisms can include medically significant organisms, which could negatively impact crew health and performance.

HLS-HMTA-0143 Food System Waste

The system shall provide readily accessible trash collection and control of food system waste.

Rationale: Food trash is to be considered in the overall plan for all types of trash. It is important to manage any food waste to control odors and microorganism growth.

Proximity to the food preparation and consumption location facilitates ease of use and efficiency.

HLS-HMTA-0144 Sleep

The system should accommodate crew sleep.

Rationale: The management of crew sleep is defined as influencing the design, provision, and operational implementation of in-flight sleep capabilities. Environmental conditions including sound should be included in the design assessment. Sleep capabilities include sleep accommodations and sleep pattern maintenance to support circadian system function, prevent fatigue-induced errors, and preserve the ability of crewmembers to respond in contingency situations.

HLS-HMTA-0145 Sleep Accommodation

The system should provide volume, restraint, accommodations, environmental control (e.g., vibration, lighting, noise, and temperature), and degree of privacy for sleep for each crewmember, to support 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 in order to ensure adequate sleep and maintain 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.)

HLS-HMTA-0146 Partial-g Sleeping

The system shall provide for horizontal sleep surface areas for partial-g environments.

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

HLS-HMTA-0147 Clothing

The system shall accommodate mass, volume for crew clothing per Attachment I – GFE List - Details.

HLS-HMTA-0148 Architecture

The system should adhere to best practices in the implementation of architecture to accommodate human users in the relevant-gravity environment.

Rationale: 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. Consideration of tasks performed in microgravity as well as lunar gravity should be assessed.

HLS-HMTA-0149 Volume Allocation

The system shall provide the volume (operational envelope) and interior configuration necessary for the crew to perform all mission tasks, using necessary tools and equipment to meet mission goals and objectives and support human performance and behavioral health.

Rationale: Adequate internal size, in terms of volume and surface area, are to be provided to ensure crewmembers can safely, efficiently, and effectively perform mission tasks, including work, sleep, eat, egress, ingress, maintenance, housekeeping, and other tasks necessary for a safe and successful mission. It is important to consider all types of volume–pressurized, habitable, and net habitable when determining the amount of volume that is necessary. Confinement, isolation, and stress that can accompany a space mission tend to increase with duration. This creates a psychological need for additional volume. Privacy becomes more important for crewmembers as mission durations become longer. When evaluating the net habitable volume and interior configuration needs of a system, careful consideration should be given to cultural attitudes with regard to the overall work space.

HLS-HMTA-0150 Volume for Crewmember Accommodation

The system shall provide the volume necessary to accommodate the expected number of crewmembers.

Rationale: Volume needed by each crewmember's activity is to be increased to allow for the interaction of the crewmembers and for safe ingress/egress to the worksite. The designer is to be careful not to assume that volume for any particular activity is not encumbered by the presence of other crewmembers. The interaction of planned activities throughout the mission is to be addressed for its activity volume and location

within the spacecraft. Activities that infringe upon the volume of other crewmembers are to be avoided by scheduling or through design of the work volume size and configuration.

HLS-HMTA-0151 Volume for Mission Accommodation

The system shall provide the volume necessary to accommodate the number of mission and contingency days.

Rationale: Increasing mission duration requires expansion in the physical volume to accommodate mission tasks and personal needs. The total required net habitable volume (NHV) per crewmember and per total crew complement increases with duration, particularly if the mission is not able to be logistically resupplied. Mission and volume designers are to carefully analyze volume needs of the crew, crew equipment, storage, and trash containment volumes to ensure they are adequately sized to provide adequate NHV for the crew to effectively and efficiently perform mission objectives.

HLS-HMTA-0152 Functional Arrangement

Habitability functions should 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.

HLS-HMTA-0153 Interference

The system should 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.

HLS-HMTA-0154 Spatial Orientation

Interface elements within a crew station shall be consistent in spatial orientation.

Rationale: Whenever possible, a consistent directional orientation is to be established for the entire spacecraft. In a 1-g or partial-g environment, orientation is not a particular problem. Down is the direction in which gravity acts, and the human is normally required to work with feet down and head up. In a microgravity environment, the human working position is arbitrary. There is no gravity cue that defines up or down. In microgravity, orientation is defined primarily through visual cues, which are under the control of the system designer. Several orientation factors to be considered when designing for a microgravity environment include work surfaces, training and testing, disorientation, visual orientation cues, and equipment operation.

HLS-HMTA-0155 Consistent Orientation

In microgravity, the system shall establish a local vertical orientation.

Rationale: In microgravity, orientation is defined primarily through visual cues, which are under the control of the system designer. The orientation within a particular crew station is referred to as a local vertical. Several orientation factors to be considered when designing a microgravity environment include work surfaces, training and testing, disorientation, visual orientation cues, and equipment operation.

HLS-HMTA-0156 Interface Orientation

Interface elements within a crew station shall have the same orientation in roll as the sagittal plane of the crewmember’s head.

Rationale: Maintaining a consistent orientation of interfaces and their elements 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 and errors. Given the complexity of some operations, e.g., piloting, a single orientation for all controls, displays, and labels may not be possible; but every effort is to be made in design to minimize crewmember repositioning required to efficiently perform a task. This requirement is meant to ensure that all equipment at an interface is aligned with the crewmember's head, even if the head is turned, 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.

HLS-HMTA-0157 Location Identifiers

A standard location coding system should 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 and serves as a communication and SA tool when traversing the vehicle or unstowing/stowing equipment. An example of Shuttle location coding is the numbering of middeck lockers: locker MF28H is located on the middeck (M), forward (F) surface, 28% of the way to the right of the total width of the surface, and 122 cm (48 in) from the top of the surface. (H indicates eight alphabetic increments of 15.2 cm (6 in) from the top.)

HLS-HMTA-0158 Location Aids

The system should 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.

HLS-HMTA-0159 Visual Distinctions

The system should provide visual distinctions for adjacent but functionally separate workstations.

Rationale: Crewmembers need easy-to-read visual cues to help them quickly adjust their orientation to a normal position. These visual cues are to define a horizontal or vertical reference plane. When adjacent workstations have vertical orientations differing by 45 degrees or greater, visual demarcations are to prevent inadvertent use of other workstation elements.

HLS-HMTA-0160 Internal Translation Paths

The system should provide intravehicular activity (IVA) translation paths to allow for the movement of crew and equipment within the time constraints of both nominal operational, contingency, and emergency conditions.

Rationale: Translation paths are needed to support the safe and efficient movement of the crew and equipment throughout the vehicle. The pathway design is to take into account the type and level of activity that occur at each of the workstations, the required movement of crew and equipment between them, the location of workstations, the number of crew, and the types of equipment being translated. As an example, lessons learned from the ISS indicate that translation paths around the ISS eating area have disrupted crew rest and relaxation required during meals.

HLS-HMTA-0161 Emergency Translation Paths

The spacecraft (excluding spacesuits) shall be configured such that the crew can ingress or egress (including hatch operation, if applicable) within the time required to preserve crew health and safety in the event of an emergency.

Rationale: System developers need to define emergency escape routes early in the design process to ensure they are functional. The routes need to be free of obstructions (snags, protrusions, stowed items, etc.), clearly marked, illuminated for emergency operations, and require a minimal number of operations for passage (such as awkward turns or hatch operations). 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.

HLS-HMTA-0162 Ingress, Egress and Escape Translation Paths

The system shall provide translation paths for ingress, egress, and escape of suited crewmembers.

Rationale: Suited crewmembers are to be able to get in and out of the vehicle on the Lunar surface or transfer between two docked vehicles in flight easily and quickly.

HLS-HMTA-0163 Translation Path Interference

Translation paths should allow movement of crew and equipment without interfering with crew activities.

Rationale: Traffic flow is not to interfere with other unrelated operational and recreational activities of the crew. These activities may include sensitive spacecraft control, routine servicing, experimentation, eating, sleep, and relaxation.

HLS-HMTA-0164 Simultaneous Use

Where appropriate, the translation path size should accommodate simultaneous use by crewmembers.

Rationale: Given the limited volume of spacecraft, movement of crewmembers simultaneously can be expected. The crew may be suited or unsuited, pressurized or unpressurized. Simultaneous use can occur in both nominal and emergency situations. The number of crew and the expected tasks to be performed are to be considered to size the translation pathway.

HLS-HMTA-0165 Hazard Avoidance

Translation paths shall be designed to prevent exposure to hazards.

Rationale: Translation pathways are to be clear of protrusions and minimize the possibility of entanglement of translating crewmembers or equipment with loose objects such as restraints, cables, hoses, or wires. Intersecting translation paths with heavy traffic flow are to minimize collisions so that damage does not occur to nearby equipment.

HLS-HMTA-0166 Path Visibility

Emergency paths shall be marked and be visible under nominal operational, contingency, and emergency conditions.

Rationale: The possibility exists for a spacecraft or subsystem failure or damage that could require evacuation, thus impacting the design for traffic flow. Crewmembers are to be provided with escape routes for egress and isolation in the event of the need for an emergency egress from their immediate location. Entry and exit pathways are to be protected; the pathways are to be free from obstruction and without dead-end corridors and marked to establish the safe and efficient movement of the crew and equipment.

HLS-HMTA-0167 Crew Ingress/Egress Translation Path in Space

The system shall provide an in-space translation path for assisted ingress and egress of an incapacitated suited or unsuited crewmember.

Rationale: Incapacitated, pressurized-suited crewmembers may be unable to ingress the vehicle or spacecraft on their own and may also be in a constrained position that requires assistance. This may include ingress from EVA or ingress/egress to/from the spacecraft from EVA or any vehicle or module to which the spacecraft is docked. A crewmember in a pressurized suit is the bounding case. This requirement also includes assisted ingress and egress for crewmembers in unpressurized suits, as well as unsuited crew.

HLS-HMTA-0168 Translation Paths for Suited Crewmembers

The expected translation paths shall be large enough to accommodate a suited crewmember and the motions necessary for translation.

Rationale: Translation paths support the safe and efficient movement of the crew. Suited crewmembers are to be able to get in and out of the vehicle on the ground or transfer between two docked vehicles in flight easily and quickly. Incapacitated pressurized-suited crewmembers may be unable to ingress on their own and may also

be in a constrained position that requires assistance. This may include ingress from EVA or ingress/egress from EVA or docked vehicles. "Crewmember in a pressurized suit" is the bounding case.

HLS-HMTA-0169 EVA Translation Path Hazard Avoidance

EVA translation paths shall prevent exposure to 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, 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.

HLS-HMTA-0170 Hatches - Initial

The System shall provide hatches that are operable by a single crewmember.

Rationale: Hatches are essential structures for vehicle function during transit and when docked to other vehicles. Hatch design must address usability not only for efficient operation by crew members but to ensure crew safety during nominal and contingency operations. Hatch operation includes unlatching/opening or closing/latching the hatch. Safety considerations include isolation of the vehicle from other vehicles in an emergency (i.e. depress, fire, toxic spill); therefore, hatches should be capable of operation from both sides; operation by one crew member; operation in no more than 60 seconds; operation without the use of tools; manual pressure equalization from the inside and outside of the hatch; providing direct pressure difference measurements on the inside and outside; and enabling visual inspection of the adjacent volume through a closed hatch. To promote usability of hatches, designers should consider providing indications of pressure and temperature to the crew prior to opening a hatch; indication of open or closed status; preventing inadvertent opening prior to complete pressure equalization; and ensuring hatch covers allow for unrestricted flow of traffic. IVR compatibility is required for uncrewed mission phases.

HLS-HMTA-0171 Hatch Cover and Door Operation without Tools

Hatch covers and doors shall be unlatched and opened and latched and closed without the use of tools from either side by a single suited crewmember.

Rationale: Hatch operation includes unlatching/opening or latching/closing the hatch. Lost or damaged tools prevent the hatches from being opened or closed, which may result in loss of crew (LOC) or loss of mission (LOM). Ground operation of flight

vehicle hatches and suited crew operation of hatches in the ground safe haven following emergency pad egress are not to require the use of tools.

HLS-HMTA-0172 Unlatching Hatch Covers

Hatch covers 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.

HLS-HMTA-0173 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.

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 from implementing more strict design requirements. For emergency hatch operating time, see section 8.3.2, Emergency Translation Paths [V2 8014], in this NASA Technical Standard.

HLS-HMTA-0174 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 in the Physical Capabilities and Characteristics reference document for the worst-case pressure differential and anticipated encumbering equipment and clothing.

Rationale: All crewmembers are to be able to operate hatches and their covers 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.

HLS-HMTA-0175 Hatch Cover and Door Gravity Operations

Hatch covers and doors shall be operable in all expected gravity conditions and orientations to which they are exposed.

Rationale: Hatches and doors are critical to the safety of the crew and vehicle, not only for maintenance of the pressure environment but also for the ability to isolate interior portions of the spacecraft if necessary. Whether designed for a vehicle that

operates in microgravity or on a planetary surface, hatches and doors are to be operable in the anticipated environment by any crewmember.

HLS-HMTA-0176 Hatch Size and Shape

Hatches and doorways shall be sized and shaped to accommodate all planned translations based on task analysis, 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 hatches and doorways while suited, especially in an emergency situation, the hatches 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 hatches and doorways. Hatch size should also consider the capability for a rescuing crewmember to be able to transport an incapacitated crewmember without being hampered by inadequate hatch or doorway sizes. Hatches and doorways may be designed to accommodate translation of robotic agents, but they must still accommodate crewmembers and their equipment.

HLS-HMTA-0177 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.

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.

HLS-HMTA-0178 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.

Rationale: Direct visual observation of the environment on the opposite side of a hatch allows the crew to determine the conditions or obstructions, such as the presence of fire or debris, on the other side of the hatch for safety purposes. Windows do not have the failure modes associated with cameras and display systems that may not be operable during emergencies when most needed.

HLS-HMTA-0179 Hatch Cover and Door Interference

When opened, hatch covers and doors shall allow for unrestricted flow of traffic.

Rationale: Open hatches 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 hatch covers and doors are to allow for a clear emergency translation pathway.

HLS-HMTA-0180 Hatch Cover Closure and Latching Status Indication

The pressure hatch covers 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. 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.

HLS-HMTA-0181 Hatch Cover Pressure Indication

Pressure hatch covers shall indicate, on 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.

HLS-HMTA-0182 Restraints

The system should provide restraints for crew use during task performance.

Rationale: In reduced gravity environments, restraints are needed by crew in order to position and stabilize themselves. Restraints are also needed to react operational forces, such as during hatch crank turning. 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, gloves, boots), movement action (e.g., single- or two-handed operation), movement 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. If task sensitivity or duration requires crew to be stabilized for a period of time, design consideration must be given to avoid pain or fatigue which can be detrimental to task performance. Body posture and joint angles must also be considered in the design and placement of restraints. For example, the neutral body posture for workstation operations in microgravity is defined in SSP 50005. Suited posture, joint angles, and range of motion are unique and must be factored into the design of suit restraints for EVAs, airlock, etc. Intentional and unintentional crew force exerted during task performance must be considered to ensure the restraints can withstand forces without failure. 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. Failures have occurred due to unplanned use of features that were not designed to withstand loads or repeated use.

HLS-HMTA-0183 Crew Restraint Provision

Crew restraints shall be provided to assist in the maintaining of body position and location in reduced gravity conditions or during high accelerations.

Rationale: Maintaining a static position and orientation at a workstation is necessary to ensure that controls can be activated without motion being imparted to the crewmember. Without gravity to hold an individual onto a standing or sitting surface, the body floats or moves in the opposite direction of an applied force. The cognitive and physical work required to maintain body position during a task can interfere with the task performance. Activities that use both hands are not to require handholds to maintain position at a workstation but may require restraints such as foot loops, straps, or harnesses. Restraints/orientation of equipment utilized during crew tasks also need to be considered when designing crew restraints.

HLS-HMTA-0184 Crew Restraint Design

Crew restraints shall be designed to accommodate the crewmember for the duration of the task.

Rationale: Crew restraints provide for operator stability. Where it is critical that a workstation operator remain stable for task performance, e.g., view through an eyepiece, operate a keyboard, or repair a circuit, foot restraints and other ad hoc positioning techniques may be sufficient. However, tasks that require a stabilized crewmember to maintain position for long periods of time, e.g., 1 hour of continuous use or longer, require a restraining system designed with task duration, stability, and training to operate in mind.

HLS-HMTA-0185 Crew Restraint Posture Accommodation

Crew restraints for microgravity applications should be compatible with the neutral body posture.

Rationale: The neutral body posture in microgravity places the human in a position unlike the vertical nature of 1-g. Most notable are changes in the angle of the foot, arm, and shoulder elevation, the forward and down head tilt, and hip/knee flexion displacing the torso backward. Crewmembers will fatigue and experience discomfort if equipment does not accommodate the neutral body posture. This can then lead to decreased performance and task execution.

HLS-HMTA-0186 Crew Restraint Interference

Crew restraints shall not interfere with crewmembers' performance of tasks.

Rationale: Some simple tasks can be easily performed with one hand while using the other hand for stability. More complex tasks, however, require coordination of both hands; and some type of body or foot restraint system may be required.

HLS-HMTA-0187 Crew Restraints for Controls Operation

Crew restraints shall provide for the operation of controls during reduced gravity, as well as during dynamic or multi-axis accelerations.

Rationale: Maintaining a position and orientation during controls operation is necessary to ensure that controls can be activated without motion being imparted to the crewmember. Restraints are meant to support and stabilize the crewmember and protect against inadvertent operation of controls.

HLS-HMTA-0188 Restraints for Suited Operations – Provision

Restraints should be placed to ensure the optimum reach and work envelope of the suited crewmember and be adjustable to maximize the work envelope.

Rationale: Suited crewmembers are not to have to reposition themselves each time they manually operate and view the vehicle's user interfaces. All vehicle seats and restraints are to be adjustable to accommodate the crewmember's ranges of motion. Crew interfaces and controls with which the suited crew interacts are to be located such that they can be reached from the restrained positions within the range of motion of the crewmember. Suits can limit the crew range of motion below the range of motion of the unsuited. Suit pressurization can further reduce the range of motion.

HLS-HMTA-0189 Mobility Aids - Initial

The system shall provide mobility aids for crew use during task performance.

Rationale: In reduced gravity environments, mobility aids (e.g., handholds) are needed by crew to stabilize themselves and translate within the environment.

HLS-HMTA-0190 Mobility Aid Standardization

Mobility aids should be standardized, clearly distinguishable, and located to aid the crew in starting or stopping movement, changing direction or speed, or translating equipment.

Rationale: Mobility aids such as hand holds 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 mobility aids, personnel may use available equipment that may be damaged from induced loads. By standardization of the 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 mobility aids from non-mobility aids that may be damaged by the application of crew-induced loads. During emergencies, crews need to be able to quickly discern mobility aids from the surrounding structures. Visual cues such as color coding may aid in this function.

HLS-HMTA-0191 Mobility Aid Structural Strength

All fixed and portable IVA mobility aids shall be designed to withstand expected forces of the crew without failure or sustaining damage.

Rationale: The tasks expected of a spaceflight crew are varied; and mobility aids are to support crewmember translation, as well as the translation of equipment or other crew, suited or unsuited, pressurized or unpressurized. Mobility aids assist in the stabilization of the crew, as well as stopping, starting, or changing of direction.

HLS-HMTA-0192 Mobility Aid for Assisted Ingress and Egress

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. 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.

HLS-HMTA-0193 Unassisted Ingress, Egress and Escape Mobility Aids

Mobility aids shall be provided for ingress, egress, and escape of crewmembers without assistance from other crew.

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. 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.

HLS-HMTA-0194 IVA Operations Mobility Aids

Where appropriate, mobility aids should be provided for the crew to conduct IVA operations.

Rationale: Mobility aids such as hand holds 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.

HLS-HMTA-0195 Mobility Aid Provision for Suited Operations

Mobility aids shall be provided along expected translation paths of suited crewmembers at an interval that accommodates the suited crewmember's reach.

Rationale: Mobility aids such as hand holds 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 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 too safely and efficiently ingress and egress the vehicle. Mobility aids designed to support pressure-suited operations are to accommodate crewmembers by providing clearance, non-slip surfaces, and non-circular handrail cross sections, and reach in between the mobility aids.

HLS-HMTA-0196 Viewing Exterior Operations - Initial

The HLS shall provide to the crew the ability to view critical external operations and events from the interior of the vehicle

Rationale: Critical external operations and events are defined as lunar operations that require a view to the exterior for mission success.
Physical windows provide direct, non-electronic, through-the-hull viewing and 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. If windows are used, best practices are found in req'ts [8045, 8046, 8043, and 8050] of NASA-STD-3001, Vol 2, Rev. B.

HLS-HMTA-0197 Window Optical Properties

System windows should have optical properties commensurate with their tasking in accordance with JSC-66320, Optical Property Requirements for Glasses, Ceramics, and Plastics in Spacecraft Window Systems.

Rationale: System windows are required to have the optical properties necessary to prevent degradation of visual acuity and optical performance. JSC-66320 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.

HLS-HMTA-0198 Window Obstruction

Window fields of view should not be obstructed or obscured in any way except for: 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.

Rationale: Fixed equipment such as window instrumentation, hardware, or a condensation prevention system that would obscure the field of view from the normal crew position for window viewing may interfere with crew tasks requiring a window.

HLS-HMTA-0199 Window Light Blocking

Each system window shall be equipped with an opaque shade or shutter that prevents external light from entering the crew compartment, such that the interior light level can be reduced to 2 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 compartments through windows.

HLS-HMTA-0200 Window Accessory Replacement/Operation without Tools

System window accessories designed for routine use should be removable and replaceable or operable from fully closed to open and vice versa by one crewmember 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.

HLS-HMTA-0201 Spacecraft Lighting - Initial

The System shall provide internal and external lighting for the illumination and indication required for all operational tasks, including landing, dependent on visible light.

Rationale: A wide range of crew and robotic tasks are expected to be performed within the vehicle. The required lighting levels vary depending on the task being performed. Examples of crew tasks include critical inspection and legibility, personal hygiene, telerobotics, and cleaning and maintenance. Examples of robotic tasks

include inspection, localization, and object identification. The combined lighting system and architectural layout are a factor in the development of a usable lighting environment. During waking hours, lighting systems must provide the crew with retinal light exposure that is sufficient in intensity, optimal in wavelength, and implemented at the proper times and durations to entrain the human circadian pacemaker to a 24-hour day and facilitate schedule shifting. Effective lighting systems for internal operational environments support human/camera color vision within the appropriate chromaticity range, color accuracy, and allow for control, position adjustment, and glare prevention. Effective lighting systems for robotics have similar characteristics, although an additional consideration is the reduction in variations in lighting across locations or time as much as possible.

HLS-HMTA-0202 Illumination Levels

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. 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.

HLS-HMTA-0203 Exterior Lighting

The system shall provide exterior lighting to aid the crew in critical events such as: assembly, maintenance, navigation, rendezvous and docking, landing, 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.

HLS-HMTA-0204 Emergency Lighting

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.

HLS-HMTA-0205 Lighting Chromaticity

Interior and exterior lighting intended for operational environments requiring human/camera color vision should 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, 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.

HLS-HMTA-0206 Lighting Color Accuracy

Interior and exterior lighting intended for human operational environments requiring photopic vision accuracy should 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 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 rendered 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.

HLS-HMTA-0207 Circadian Entrainment

Lighting systems shall provide the crew with lighting >150 lux with a blue wavelength peak to entrain the human circadian pacemaker to a 24-hour day and facilitate schedule shifting.

Rationale: Terrestrial studies demonstrate that light serves as the strongest external stimulus for maintaining our biological clock. Lighting systems are to provide the proper light for circadian entrainment to address disruptions in the sleep/wake cycles of space flight crews and maintain health and performance. Circadian entrainment depends on stale DAILY exposure to light that is sufficient for entrainment. The circadian rhythm will revert to its own endogenous period (usually longer than 24 hours) or will exhibit abnormal entrainment when lighting is insufficient or absent. One consequence of modest circadian misalignment is circadian-phase insomnia. It's important to note that in the absence of an appropriate light signal, the circadian rhythm will immediately begin to misalign, which is why it is necessary to require lighting sufficient for entrainment on short-duration missions. In order to minimize the influence on the circadian system, lighting systems for short duration vehicles should, at a minimum, ensure that white light in sleeping areas provide a general illumination setting that minimizes short-wavelength light to mitigate against inadvertently suppressing melatonin during the biological night; peripheral light sources that are enriched in short wavelength light, however, should then be made available for use as needed.

HLS-HMTA-0208 Lighting Controls

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.

HLS-HMTA-0209 Lighting Adjustability

Interior lights should 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.

HLS-HMTA-0210 Uniformity, Glare, & Shadows

HLS operational environment shall minimize glare and shadows while also providing environment that is conducive to the usage of computer display devices.

Rationale: Contrast, uniformity, direct reflections, and veiling reflections are all potential problem that are a result of a lack of coordination with the selection and placement of light sources, display devices, and architectural surface material reflection, and shape surface structures. A host of issues, largely associated with legibility, visual eye comfort, and situational awareness could occur.

HLS-HMTA-0211 Mechanical Hazard - Initial

Systems, hardware, and equipment shall be designed to protect hardware from damage and the crew from injury.

Rationale: Known mechanical hazard sources can be identified through the hazard process. 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. Additionally, all surfaces, edges, etc. should be designed to avoid burrs, sharp edges, entanglement points, etc.

HLS-HMTA-0212 Entrapment

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.

HLS-HMTA-0213 Potential Energy

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, and relying on procedures or training is the least preferred.

HLS-HMTA-0214 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.

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.

HLS-HMTA-0215 Protection

Systems, hardware, and equipment shall be protected from and be capable of withstanding forces imposed 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. Unintentional forces are addressed by compliance with LD0028 IVA Loads in JSC 65829 – Loads and

Structural Dynamics Requirements for Spaceflight Hardware. "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 provided in the strength dataset and to assume the crew could apply their maximum strength forces.

HLS-HMTA-0216 Isolation of Crew from Spacecraft Equipment

Protective provisions, e.g., close-out panels, should 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 section 9.4.1, Protection [V2 9027], 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.

HLS-HMTA-0217 Sharp Corners and Edges - Fixed

Corners and edges of fixed and handheld equipment to which the bare skin of the crew could be exposed should be rounded as specified in Tables 24 and 25 Corners and Edges I and II at the top of both tables (ref NASA-STD-3001 Vol 2, Rev B).

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 23: Corners and Edges I

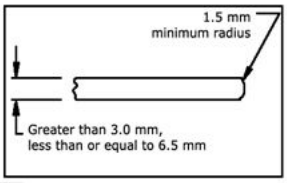
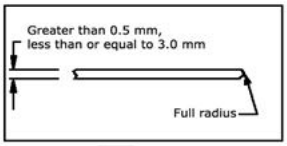
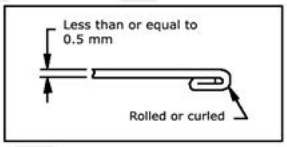
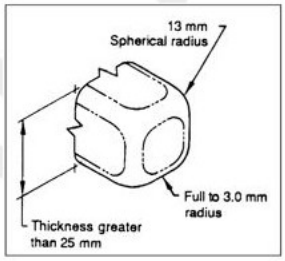
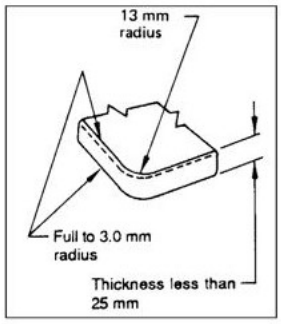
Material Thickness (t)	Minimum Corner Radius	Minimum Edge Radius	Figure
3.0 mm < t ≤ 6.5 mm (0.125 in < t ≤ 0.25 in)	6.5 mm (0.26 in)	1.5 mm (0.06 in)	
0.5 mm < t ≤ 3.0 mm (0.02 in < t ≤ 0.125 in)	6.5 mm (0.26 in)	Full radius	
t < 0.5 mm (t < 0.02 in)	6.5 mm (0.26 in)	Rolled, curled, or covered to 3.0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

Table 24: Corners and Edges II

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)	
6.5 mm < t ≤ 25 mm (0.25 in < t ≤ 1 in)	13 mm (0.5 in)	3.0 mm (0.125 in)	

HLS-HMTA-0218 Protection from Functionally Sharp Items

Functionally sharp items should 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.

HLS-HMTA-0219 Sharp Corners and Edges - Loose

Corners and edges of loose equipment to which the crew could be exposed should be rounded to radii no less than those given in Table 26, Loose Equipment Corners and Edges (ref NASA-STD-3001 Vol 2, Rev B).

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 (section 9.3.1.5, Sharp Corners and Edges–Fixed [V2 9009] in this NASA Technical Standard).

Table 25: 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)

HLS-HMTA-0220 Burrs

Exposed surfaces should 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.

HLS-HMTA-0221 Pinch Points

Pinch points should 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.

HLS-HMTA-0222 High-Temperature Exposure

Any surface to which the bare skin of the crew is exposed shall not cause epidermis/dermis interface temperature to exceed the pain threshold limit of 44 °C (111.2 °F).

Rationale: Research by Greene, L.C., et al. (1958) on human tolerance to heat pain showed that the pain threshold is reached at 43.7°C (110.6 °F) skin temperature. Lloyd-Smith, D.L., and Mendelssohn, K. (1948) found the pain threshold to be 44.6°C (112.3 °F). Defrin, et al. (2006) investigated heat pain threshold across the body and found the lowest level in the chest (42°C (107.6 °F)), the highest in the foot (44.5°C (112.1 °F)), and in the hand 43.8°C (110.8 °F). In a study by Moritz, and Henriques. (1947), 44°C (111.2 °F) was the lowest temperature at which significant epidermal damage occurred, after exposure was sustained for 6 hours. As the contact temperature increased above 44°C (111.2 °F), the time to damage was shortened by approximately 50% for each 1°C (1.8 °F) rise in temperature up to about 51°C (123.8 °F). Increasing contact pressure was not sufficient to increase the risk of thermal injury. At contact skin temperatures above 70°C (158 °F), it took less than 1 second to produce complete epidermal cell death. Pain threshold, rather than damage threshold, should be used to (a) preclude skin damage and (b) prevent a startle pain reaction, i.e., pulling a hand away quickly, which may cause injury from flailing.

HLS-HMTA-0223 Low-Temperature Exposure

Any surface to which the bare skin of the crew is exposed shall not cause skin temperature to drop below the pain threshold limit of 10 ºC (50 °F).

Rationale: Studies on the thermal performance of spacesuit gloves have shown that pain from cold occurring at hand skin temperatures of 10 ºC (50 °F) was deemed tolerable (JSC-39116, EMU Phase VI Glove Thermal Vacuum Test and Analysis Final Report; Bue, 2009). Previous research on human tolerance to cold has shown that numbness occurs at 7 ºC (44.6 °F) skin temperature (Provins and Morton, 1960) and risk of frostbite at 0 ºC (32 °F) (Havenith, G., et al. (1992)). Pain threshold, rather than damage threshold, should be used to (a) preclude skin damage and (b) prevent a startle pain reaction, i.e., pulling a hand away quickly, which may cause injury from flailing. In addition, staying above the numbness threshold is important, both because numbness can mask skin damage, which may impact flight safety, and also to allow normal touch sensation for tasks after contact with cold objects.

HLS-HMTA-0224 Equipment Handling

All items designed to be carried or removed and replaced should have a means for grasping, handling, and carrying (and, where appropriate, by a gloved hand).

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.

HLS-HMTA-0225 Electrical Hazard Protection - Initial

The system shall protect the crew and equipment from electrical hazards.

Rationale: The vehicle should engineer out electrical hazards that would expose crewmembers to electric shock, burns and electrocution.

HLS-HMTA-0226 Power Interruption

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, all circuits could require crew contact with exposed conductors. There is to be a way for the crew to eliminate this exposure. At the least, it could interfere with task performance; and, at the most, it could cause serious injury or death.

HLS-HMTA-0227 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.

Rationale: When de-energizing a system, the user should always be provided with feedback that confirms the function has occurred. 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.

HLS-HMTA-0228 Nominal Physiological Electrical Current Limits

Under nominal situations (routine human contacts to hardware), the program shall limit crew exposure to < 0.4 mA for direct current (DC) and < 0.2 mA 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

MW isolation along with grounding to conductive surfaces with Class H or better bond to prevent current flow through crew members.

HLS-HMTA-0229 Catastrophic Physiological Electrical Current Limits for all Circumstances

Any hazard analysis that determines a crew exposure to > 40mA for direct current (DC) and > 8 mA for alternating current (AC) shall be considered catastrophic to the human.

Rationale: Notes: 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 IEC60479-2 limits. For voltage spikes of short duration (< 1 second) refer to IEC60479-5 for limits (Figure 5, curve c1 for AC and Figure 14, curve c1 for DC).

The 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 maintaining muscle control if shocked to protect 99.5% of the population (IEC TR 60479-2, Figure 7). This NASA Technical Standard is intended to provide the threshold where additional engineering controls will be required to mitigate electrical shock/physiological effects to the human.

HLS-HMTA-0230 Catastrophic Physiological Electrical Current Limits for Startle Reaction

For unique situations where a startle reaction is deemed potentially detrimental (such as during manual control of a spacecraft or during an EVA), any hazard analysis that determines a crew exposure to > 2 mA for DC and > 0.5 mA for AC shall be considered catastrophic to the human.

Rationale: Note: AC voltage 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 IEC60479-2 limits.

The 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, Table 1). Under certain circumstances such as startle reaction, more restrictive thresholds than the physiological catastrophic limits of the 9.3.2.x.2 limits above 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's deemed appropriate.

HLS-HMTA-0231 Body Impedance for Voltage Calculations Utilizing Electrical Current Thresholds

The program shall use the 5th percentile values for the appropriate conditions (wet/dry, AC/DC, voltage level, large/small contact area) from IEC TR6049-1 to determine the appropriate body impedance to calculate the voltage associated with any current limit analysis.

Rationale: The IEC is the leading global organization that prepares and publishes international standards for all electrical, electronic, and related technologies. For example: 850 W 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 TR 60479-1, Table 3).

HLS-HMTA-0232 Leakage Currents – Equipment Designed for Human Contact

For equipment that is 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 27, Leakage Currents – Equipment Designed for Human Contact (ref NASA-STD-3001 Vol 2, Rev B).

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 also from the applied parts to ground. The summation of all the currents should be compared to the current limits in Table 27.

Table 26: Leakage Currents - Equipment Designed for Human Contact

Maximum Current (mA RMS)				
Body Contact	**Frequency**	**Operating Condition**	**Equipment Type**	
			Isolated Equipment	**Non-Isolated Equipment**
External*	dc to 1 kHz	Normal	0.1	
		Single Fault	0.5	
	>1 kHz	Normal	Lesser of (0.1 x frequency in kHz) or 5	
		Single Fault	Lesser of (0.5 x frequency in kHz) or 5	
Internal	dc to 1 kHz	Normal	0.01	Not Allowed
		Single Fault	0.05	
	>1 kHz	Normal	Lesser of (0.01 x frequency in kHz) or 1	
		Single Fault	Lesser of (0.05 x frequency in kHz) or 1	
*For dc, there is a small risk of heating and tissue necrosis for prolonged duration of contact.				

HLS-HMTA-0233 Minimize Fluid and Gas Spill Hazards - Initial

The system shall prevent release of fluids and gases that cause injury to the crew

Rationale: The vehicle should have designs in place to limit crew exposure to fluid and gas spills to protect crew and vehicle health.

HLS-HMTA-0417 Fluid/Gas Release

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.

HLS-HMTA-0234 Fluid/Gas Containment

The system shall provide for containment or removal of fluids and gases that might be released.

Rationale: Excess gases and fluids are likely to be released during draining and filling of systems. Designs are to accommodate these possibilities to ensure capture, containment, and disposal that is safe and effective. Capture facilities are to be located near the points where release is likely to occur (maintenance or service

points). It is understood that Appendix H Offerors can only control and remove the gases that are part of their vehicle/system or in the identified GFE list.

HLS-HMTA-0235 Fluid/Gas Isolation

The system shall provide for the isolation or shutoff of fluids and gases in hardware and equipment.

Rationale: Gases and 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.

HLS-HMTA-0237 Inflight Maintenance and Assembly - Initial

System hardware and equipment shall be designed to have minimal maintenance needs and have physical attributes that prevent incorrect or incomplete mating, installation, or mounting during expected mission tasks.

Rationale: Inflight maintenance and assembly of hardware items will likely be required on these missions. To reduce crew time, error and malfunctions, systems should be designed to prevent errors in assembly and disassembly.

HLS-HMTA-0238 Connector Spacing

The spacing between connectors should 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.

HLS-HMTA-0239 Connector Actuation without Tools

Connectors shall be operable without tools for mating and demating.

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.

HLS-HMTA-0240 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.

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.

HLS-HMTA-0241 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.

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.

HLS-HMTA-0242 Cable Management

The system should 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. 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. 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.

HLS-HMTA-0243 Cable Identification

All maintainable cables, wires, and hoses should 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.

HLS-HMTA-0244 Design for Maintenance

The system should provide the means necessary for the crew to safely and efficiently perform routine service, maintenance, and anticipated unscheduled maintenance activities.

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.

HLS-HMTA-0245 Commercial Off-the-Shelf Equipment Maintenance

Maintenance for commercial off-the-shelf equipment should be suitable to the spaceflight 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.

HLS-HMTA-0246 In-Flight Tool Set

Each program shall establish a set of in-flight tools necessary to maintain or reconfigure the spaceflight system.

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. 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.).

HLS-HMTA-0247 Maintenance Time

Planned maintenance for systems and associated hardware and equipment shall be capable of being performed within the allotted crew schedule.

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, supplies, training, and documentation necessary for crews to maintain efficient and safe operations.

HLS-HMTA-0248 Minimizing Maintenance

All systems and equipment should be designed to reduce the need for maintenance.

Rationale: Maintenance and servicing are directly related to 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, supplies, training, and documentation necessary for crews to maintain efficient and safe operations.

HLS-HMTA-0249 Equipment Modularity

Where possible, equipment should be replaceable as modular units.

Rationale: Modular units can reduce maintenance times by eliminating removal, replacement, and checkout of individual components. Modular units may also reduce training times.

HLS-HMTA-0250 Captive Fasteners

Fasteners used by the crew during maintenance should be captive.

Rationale: 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.

HLS-HMTA-0251 Minimum Variety of Fasteners - System

The system should 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.

HLS-HMTA-0252 Maintenance Item Location

The system should 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.

HLS-HMTA-0253 Check and Service Point Accessibility

Check points and service points for systems, hardware, and equipment should be directly accessible.

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.

HLS-HMTA-0254 Maintenance Accommodation

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.

HLS-HMTA-0255 Visual Access for Maintenance

Maintenance tasks that require visual feedback should be directly visible during task performance.

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.

HLS-HMTA-0256 Hand Clearance for Maintenance

Clearance should be provided for the crewmember to obtain hand access required for performing maintenance tasks, while wearing the most encumbering equipment and clothing anticipated.

Rationale: Hand clearance for in-flight maintenance tasks is to be provided by the hardware developer to ensure that maintenance tasks can be performed. Determination of anticipated parameters can be made through a detailed task analysis.

HLS-HMTA-0257 Tool Clearance

The system should 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.

HLS-HMTA-0258 Fault Detection

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 so as 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.

HLS-HMTA-0259 Failure Notification

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 so as to minimize additional training.

HLS-HMTA-0260 Protective Equipment

The system shall provide Personal Protective Equipment, hardware, and operations specific to the providers known vehicle hazards.

Rationale: Protective equipment shall be provided 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. 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.

HLS-HMTA-0261 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 MCC.

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.

HLS-HMTA-0262 Minimum Number of Fasteners - Item

For items that may be serviceable by the crew, the number of fasteners used should 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.

HLS-HMTA-0263 Protective Equipment Automation

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.

HLS-HMTA-0264 Use of Hearing Protection

The system shall meet SPL limits of requirements HLS-HMTA-0067 through HLS-HMTA-0082, except where otherwise specified, 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 ascent and landing, 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.

HLS-HMTA-0266 Hearing Protection Interference

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.

HLS-HMTA-0267 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.

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 anticipated fires (large fires or fires where crew could be absent). 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.

HLS-HMTA-0268 Fire Protection System Health and Status

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.

HLS-HMTA-0269 Fire Protection System Failure Alerting

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.

HLS-HMTA-0270 Fire Protection System Activation

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.

HLS-HMTA-0271 Portable Fire Extinguishers

A fire protection system shall include manually operated portable fire extinguishers.

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.

HLS-HMTA-0272 Emergency Equipment Accessibility

Emergency equipment shall be clearly identified, accessible, and useable to complete emergency response in the time required.

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.

HLS-HMTA-0273 Operability

The system shall provide crew interfaces are operable in the expected flight configuration with an acceptable task performance.

Rationale: The system design for any tasks requiring crew interaction must provide an effective and efficient interface that allows the crew to successfully achieve necessary function or outcome. Crew achieve mission objectives through tasks involving monitoring, operating, or maintaining with required accuracy (effectiveness), timeliness (efficiency) and usability. Designs shall accommodate suited and unsuited crews as defined in task analyses.

HLS-HMTA-0274 Usability Acceptance Criteria

The system shall provide crew interfaces that have a minimum average satisfaction score of 85 as measured by the System Usability Scale (SUS).

Rationale: Usable crew interfaces allow users to achieve task goals efficiently, effectively, and with satisfaction (ISO-9241-11). Efficiency, effectiveness, and satisfaction are the three major components of usability; therefore, acceptance criteria for all three should be defined by every program. Usability testing must be part of the verification process. Effective crew interfaces allow users to achieve specified tasks with accuracy and completeness. Efficient crew interfaces allow users to expend appropriate amounts of resources, e.g., time, workload, to achieve the effectiveness necessary in a specified context of use. Users are satisfied with a crew interface if they are willing to use a crew interface and have positive subjective responses and attitudes toward the crew interface. The SUS scale and information on scoring and interpreting results can be found at https://measuringu.com/sus.

HLS-HMTA-0275 Crew Interface Effectiveness

The system shall provide crew interfaces that enable the crew to perform their tasks effectively, i.e., within acceptable error limits and scheduled operating times.

Rationale: For optimal safety and productivity, crew interfaces are to support crew performance effectively with minimal errors. Errors are defined as 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. Usability errors include missed or incorrect inputs or selections, navigation errors, loss of SA, and inability to complete a task. The usability error rate is to be computed as a percentage and is to be calculated from the ratio of the number of task steps performed erroneously to the number of total task steps. A minimal impact error is defined as an error that does not result in a change to the system state, like vehicle or mission-critical robotics. Each program needs to define acceptable error limits and operating times based on detailed task analysis.

HLS-HMTA-0276 Crew Interface Efficiency

The system should provide crew interfaces that are efficient, e.g., with reduced training time, task time, and frustration.

Rationale: Efficiency is determined by time on task, number of errors made, and the training demands. Maximizing efficiency should not be achieved through high training demands or performance pressure. Crew interfaces that do not maximize efficiency can result in frustration.

HLS-HMTA-0277 Crew Interfaces Standardization

Crew interfaces should 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.

HLS-HMTA-0278 Operations Nomenclature Standardization

Operational nomenclature should be standardized throughout a system.

Rationale: It is imperative that spaceflight 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 commands, procedures, displays, planning products, reference information, system handbooks, system briefs, mission rules, schematics, and payloads operations products.

HLS-HMTA-0279 Display Standards, Labelling Plan, and Icon Library

Each program should establish display standards, a labelling plan, and an icon library.

Rationale: A program-wide label plan is to explicitly specify the characteristics of labels such as font, size, style, color, etc., and includes many example pictures. A display standards document subsequently results in increased usability and safety since the plan enforces standardization. It also results in cost savings, since the plan simplifies label verification.

HLS-HMTA-0280 Units of Measure

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.

HLS-HMTA-0281 Crew Interface Operations Standardization

Methods of operating crew interfaces should 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.

HLS-HMTA-0282 Consistent Displays and Controls

Crew interfaces should 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.

HLS-HMTA-0283 Displays and Controls Commonality

Display and control interfaces performing similar functions should 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.

HLS-HMTA-0284 Consistent Procedures

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.

HLS-HMTA-0285 Display and Control Distinctions

Display and control actions that result in different outcomes should 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.

HLS-HMTA-0286 Syntax Distinction

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 data base.

HLS-HMTA-0287 Use of Cues

Crew interfaces should use 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.

HLS-HMTA-0288 Cue Saliency

Cues should be used such that the saliency of the cue is 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.

HLS-HMTA-0289 System Health and Status

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.

HLS-HMTA-0290 System Messages

System messages should 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.

HLS-HMTA-0291 Display Update

Data should be updated for display within 1.0 second of the crew-commanded state change.

Rationale: When a change to vehicle state occurs, that change is to be reflected on the display monitor within 1.0 second. State changes are changes to the configuration or functional state of vehicle subsystems and components. A state change can be hardware or software. Excessive delays in the presentation of information lead to a decrease in productivity and an increase in frustration.

HLS-HMTA-0292 Missing Data Display

When the display of a data parameter cannot be completed because it is missing or unavailable, the system should provide feedback to the crew within the time specified in Table 28, Maximum System Response Time(s) (ref NASA-STD-3001 Vol 2, Rev B).

Rationale: Feedback on data that are unavailable, i.e., lost or stale, is important to the crew for accurately weighing data during troubleshooting and decision-making periods.

Table 27: Maximum System Response Time(s)

System Response	System Response Time (s)
Indication of a discrete input, e.g., keystroke	0.1
Display of information on crew request	1.0
Local update of crew selection, e.g., menu	0.5
Display of updated data on crew command of state change	1.0
Feedback that the crew's command is in progress, completed, or cannot be completed	2.0

HLS-HMTA-0293 Control Feedback

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.

HLS-HMTA-0294 System Feedback

The system should provide feedback to the crew in accordance with the system response times in Table 28.

Rationale: Response times that are too long will impair interaction, often resulting in additional, redundant inputs, errors, and frustration. Minimizing variability in response time is also important.

HLS-HMTA-0295 Current Procedure Step

The system should 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.

HLS-HMTA-0296 Completed Procedure Steps

The system should 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.

HLS-HMTA-0297 View of Procedure Steps

The system should 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.

HLS-HMTA-0298 Procedure Flexibility

The system should 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.

HLS-HMTA-0299 Controllability and Maneuverability (Manual Control)

The system 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.

Level 2 or better handling qualities (HQR 1-6) are acceptable during manual control in all other scenarios.

Rationale: 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 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.]. L1 is only required for scenarios where manual control is the primary control method or in scenarios where the automatic flight control system is non-operational. L2 is good at all other times.

HLS-HMTA-0300 Tolerate Inadvertent Operator Action

The system shall be designed to tolerate inadvertent operator action, including within the presence of any single system failure, as identified by the human error analysis, without causing a catastrophic event.

Rationale: The human error analysis includes all mission operations while the crew is interacting with the space system - including crew and MCC operations, and ground processing operations with flight crew interfaces. This analysis covers response to system failures and abort scenarios. The appropriate level of protection (i.e., one, two, or more inadvertent actions) is determined by the integrated human error and hazard analysis. An operator is defined as any human that commands or interfaces with the space system during the mission, including humans in the control centers.

When designing against system failure, the intent is to provide a robust system interface design that cannot be defeated by a system failure. Where the system is designed to protect for more than one inadvertent action, the level of protection after a single system failure may be reduced, but still protects from a single inadvertent operator action. In addition, this ensures that back-up capabilities maintain the same-level of tolerance to human error as the primary system

HLS-HMTA-0301 Inadvertent Operation Prevention

Control systems shall be designed to prevent inadvertent operation.

Rationale: This requirement allows for the design to preclude inadvertent operation. 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.

HLS-HMTA-0302 Inadvertent Operation Recovery

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.

HLS-HMTA-0303 Control for Human Error

The system shall implement controls to human error according to the following precedence:
a. Prevent human error in the maintenance, operation, and control of the system.
b. Reduce the likelihood of human error and provide the capability for the human to detect and correct or recover from the error.
c. Design the system to limit the negative effects of errors in accordance with NASA-STD-3001, Vol 2 Rev B Section 10.1.8 Error Prevention and Recovery

Rationale: Human error is either an action that is not intended or desired by the human or a failure on the part of the human to perform a prescribed action within specified limits of accuracy, sequence or time that fails to produce the expected result and has led or has the potential to lead to an unwanted consequence. Controlling Human Error requires identification of human errors through human error analysis (HEA). The HEA is a systematic approach to evaluate human actions, identify potential human error, model human performance, and qualitatively characterize how human error affects a system. HEA provides an evaluation of human actions and error

in an effort to generate system improvements that reduce the frequency of error and minimize the negative effects on the system. The human error analysis considers mission operations while the crew is interacting with the space system - including crew operations, ground control operations (typically covered via hazard reports), and ground processing operations with flight crew interfaces. The analysis also covers response to system failures and abort scenarios. The effectiveness of the HEA is dependent on its integrated use in design activities, upgrades, enhancements, and operation-risk trades.

The intent of the human error analysis is to:
1) Identify inadvertent operator actions which would cause a catastrophic event and determine the appropriate level of tolerance;
2) Identify other types of human error that would result in a catastrophic event (e.g., operational errors, errors of omission, timing errors).
3) Apply the appropriate error management as described in this requirement.

HLS-HMTA-0304 Design Induced Crew Error

The system shall provide crew interfaces that result in a maximum of 5% erroneous task steps per user, where each erroneous task step is committed by 10% or fewer users. Note: the system includes hardware, software, and operating procedures.

HLS-HMTA-0305 Crew Control of Vehicle

The system shall provide the capability for the crew to monitor, operate, and control the integrated space vehicle and subsystems, where:
a. The capability is necessary to execute the mission.
b. The capability would prevent a catastrophic event.
c. The capability would prevent an abort.

Rationale: This capability flows directly from the definition of certifying the integrated space vehicle to function with the crew during all flight phases. Within the context of this requirement, monitoring is the ability to determine where the vehicle is, its condition, and what it is doing. Monitoring helps to create situational awareness that improves the performance of the human operator and enhances the mission. Determining the level of operation over individual functions is a decision made separately for specific space systems. Specifically, if a valve or relay can be controlled by a computer, then that same control could be offered to the crew to perform that function; however, a crewmember probably could not operate individual valves that meter the flow of propellant to the engines, but the function could be replaced by a throttle that incorporates multiple valve movements to achieve a desired end state (reduce or increase thrust). Meeting any of the three stated conditions invokes the requirement. The first condition recognizes that the crew performs functions to meet mission objectives and, in those cases, the crew is provided the designated capabilities. This does not mean that the crew is provided these capabilities for all

elements of a mission. Many considerations are involved in making these determinations, including capability to perform the function and reaction time. The second and third conditions recognize that, in many scenarios, the crew improves the performance of the system and that the designated capabilities support that performance improvement. It is recognized that there are situations where it is not feasible to provide the crew the capability to prevent an abort. For example, during ascent aborts, the time to detect an abort condition and activate the abort system may be less than the time for the crew to evaluate the condition, make a determination they must prevent an abort, and then perform the necessary tasks to prevent the ascent abort.

HLS-HMTA-0306 Control Shape

The shape of a control should not interfere with ease of control manipulation.

Rationale: 2) Identify other types of human error that would result in a catastrophic event (e.g., operational errors, errors of omission, timing errors).

HLS-HMTA-0307 Control Identification

Controls that are intended for out-of-view operation shall be spatially or tactually distinct from one another.

Rationale: 3) Apply the appropriate error management as described in this requirement.

HLS-HMTA-0308 Emergency Control Coding

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.

HLS-HMTA-0309 Control Size and Spacing

The size and spacing of controls should 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.

HLS-HMTA-0310 Control Arrangement and Location

The arrangement and location of functionally similar or identical controls should 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.

HLS-HMTA-0311 Control Proximity

Controls used by a restrained or unrestrained crewmember should 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.

HLS-HMTA-0312 Control Operation during Accelerations

The system should 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.]

HLS-HMTA-0313 Control Operating Characteristics

Controls should 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 should be evaluated in conjunction with handling qualities, controllability, and maneuverability.

HLS-HMTA-0314 Control Input-Response Compatibility

Controls should 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, should system responses not be compatible with input directions.

HLS-HMTA-0315 Control Latency

The system should 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.

HLS-HMTA-0316 Control Resistive Force

Control resistive force should 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.

HLS-HMTA-0317 Detent Controls

Detent controls should 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.

HLS-HMTA-0318 Stops Controls

Stops should 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.

HLS-HMTA-0319 Command Confirmation

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.

HLS-HMTA-0320 Crew Interface Commonality

Hardware and equipment performing similar functions should have commonality of crew interfaces.

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

HLS-HMTA-0321 Differentiation

Hardware and equipment that have the same or similar form but different functions should 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.

HLS-HMTA-0322 Routine Operation

Interactions with and operation of systems, hardware, and equipment used during routine/nominal operations should not consume an inordinate amount of time such that it disrupts tasks and discourages crew performance of tasks.

Rationale: Good design of systems and equipment can reduce the amount of time to perform many routine tasks, i.e., 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 alacrity helps ensure proper use.

HLS-HMTA-0323 Training Minimization

Hardware and equipment that crew interact with should 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, 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.

HLS-HMTA-0324 Suited Control Operations

Controls to be used by suited crewmembers should 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.

HLS-HMTA-0325 Suited Control Spacing

Controls to be used by suited crewmembers should 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.

HLS-HMTA-0326 Information Design - Initial

The system shall provide information needed for mission planning, mission operations, system maintenance, and system health and status in a form that does not require mental transposition or computation, memory, or repetitive navigation.

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. Information displays include electronic and non-electronic media (e.g., fixed or mobile electronic displays, labels, procedures, placards). Data may be presented on different displays including mobile devices that are an extension of other display devices or an independent device. Task analysis helps to define data and level of detail needed for crew task performance.

HLS-HMTA-0327 Display and Control Location and Design

Displays and controls should 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) and expected crew postures (e.g., suited, 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.

HLS-HMTA-0328 High Priority Displays and Controls

Emergency, critical, important, and most frequently used displays and controls should be located in the most prominent crew viewing and operating zones.

Rationale: During the design process, trade-off 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 should be determined through a detailed task analysis.

HLS-HMTA-0329 Display and Control Grouping

Displays and controls should 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 should be determined through a detailed task analysis.

HLS-HMTA-0330 Display-Control Relationships

All display-control relationships should 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.

HLS-HMTA-0331 Display and Control Movement Compatibility

Displays should 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 should be relative to this point of view. This helps ensure easy understanding of relations between controls and displays.

HLS-HMTA-0332 Display and Control Sequence of Use

Displays and controls should 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.

HLS-HMTA-0333 Display Identifying Features

Displays should 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.

HLS-HMTA-0334 Display Area

The system should 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.

HLS-HMTA-0335 Display Interpretation

Displays should 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.

HLS-HMTA-0336 Display Readability

Displays should be readable by the crew from the crew'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.

HLS-HMTA-0337 Display Information

Information displayed should 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 situational awareness and increases the chances of an error. Appropriate display content can be determined by task analysis.

HLS-HMTA-0338 Display Information Flow

Information displayed should be grouped, arranged, and located to support task flow.

Rationale: The information displayed should 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 should be determined through a detailed task analysis.

HLS-HMTA-0339 Display Navigation

Display navigation should allow the crew 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 crew'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.

HLS-HMTA-0340 Display Nomenclature

The nomenclature for each item or process should 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.

HLS-HMTA-0341 Display Coding Redundancy

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.

HLS-HMTA-0342 Measurement Units

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.

HLS-HMTA-0343 Visual Display Legibility

Displays should 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.

HLS-HMTA-0344 Visual Display Parameters

The system should provide displays that meet the visual display requirements in Table 29, Visual Display Parameters (ref NASA-STD-3001 Vol 2, Rev B).

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 crew.

Table 28: 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	
	2^{12} (4,096)	--	Text and graphics displays	
Number of gray levels	2^8 (256)	--	B/W image and video displays	
Note: 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.				

HLS-HMTA-0345 Visual Display Character Parameters

The system should provide displays that meet the visual display character requirements in Table 30, Visual Display Character Parameters Maximum Permissible Exposure (MPE) Limits (ref NASA-STD-3001 Vol 2, Rev B).

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 29: 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)

HLS-HMTA-0346 Display Font

Font size and type should 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.

HLS-HMTA-0347 Intelligibility of Electronically Stored Speech Messages

Electronically stored speech messages from audio displays should 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.

HLS-HMTA-0348 Sound Pressure Level

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.

HLS-HMTA-0349 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.

Rationale: Auditory displays are to be audible as well as interpretable by the crew. This helps makes sure that appropriate responses are taken as needed.

HLS-HMTA-0350 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.

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.

HLS-HMTA-0351 Information Management Methods and Tools

The information management system should 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.

HLS-HMTA-0352 Information Management Standard Nomenclature

The information management system should 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.

HLS-HMTA-0353 Information Management Compatibility

The information management system should 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 spacecraft systems. Requirements are to ensure that the systems work together successfully and efficiently to ensure task and mission success.

HLS-HMTA-0354 Information Management Operation Rate

The information management system should 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.

HLS-HMTA-0355 Information Management Data Provision

The information management system should 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.

HLS-HMTA-0356 Information Management Security

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.

HLS-HMTA-0357 Information Management Ground Access

The information management system should 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.

HLS-HMTA-0358 Information Capture and Transfer

The information management system should 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.

HLS-HMTA-0359 Information Annotation

The information management system should 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.

HLS-HMTA-0360 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.

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.

HLS-HMTA-0361 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.

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.

HLS-HMTA-0362 Software System Recovery

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.

HLS-HMTA-0363 Communication System Design

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.

HLS-HMTA-0364 Communication Capability

The system shall provide the capability to send and receive communication among crewmembers, spacecraft systems, and MCC systems to support crew performance, behavioral health, and safety.

Rationale: Communication capabilities are necessary to enable information exchange in order 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 (intravehicular activity (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.

HLS-HMTA-0365 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.

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.

HLS-HMTA-0366 Communication Operational Parameters

To ensure intelligibility, audio communications should address 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.

HLS-HMTA-0367 Communication Environmental Parameters

To ensure intelligibility, audio communications should address 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

HLS-HMTA-0368 Communication Controls and Procedures

To ensure intelligibility, audio communications should 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.

HLS-HMTA-0369 Communication Transmitter and Receiver Configuration

To ensure intelligibility, audio communications should 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

HLS-HMTA-0370 Audio Communications Quality

Audio communication speech quality should ensure that auditory speech communications do 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.

HLS-HMTA-0371 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.

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: Section 10.5.3.7, Word Recognition [V2 10091, in this NASA Technical Standard is not meant to apply to speech recognition software.

HLS-HMTA-0372 Private Audio Communication

The system shall provide the capability for private audio communication with the ground.

Rationale: Private communication capabilities are to exist for the crew to discuss topics such as family, health, and medical issues with the ground in private.

HLS-HMTA-0373 Video Communications Visual Quality

Video communications should 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.

HLS-HMTA-0374 Video Communications Spatial Resolution

Video communications should 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.

HLS-HMTA-0375 Video Communications Temporal Resolution

Video communications should 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.

HLS-HMTA-0376 Video Communications Color and Intensity

Video communications should 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.

HLS-HMTA-0377 Video Communications Bit Rate

Video communications systems should 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.

HLS-HMTA-0378 Audio-Visual Lag Time

Communications systems that carry sound and video that are intended to be synchronized should 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 should not have time lag that can cause perceptual difficulties for the crew. When listening to human speech, even small lags between audio and video can be noticeable and disturbing.

HLS-HMTA-0379 Caution & Warning (C&W) Annunciation - Initial

The system shall detect, report, and annunciate faults for alerts, caution, warning, and emergency events to the crew, ground, Visiting Vehicle, and/or autonomous operations.

Rationale: Off-nominal events are usually divided into the following four categories to simplify training and user comprehension: emergencies, warnings, cautions, and alerts (action required events). During off-nominal events, crew attention should be directed to commensurate with the urgency of the situation and the use of multiple modalities, e.g., both visual and auditory, provides redundancy to ensure the attention of the crew; except for advisories, which may not have an auditory annunciation. Annunciation to crew shall include audible notification.

HLS-HMTA-0380 Distinguishable and Consistent Alarms

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.

HLS-HMTA-0381 Audio Display Sound Level

Alarms shall produce 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).

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.

HLS-HMTA-0382 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.

Rationale: This 0.6-second 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).

HLS-HMTA-0383 Frequency

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.

HLS-HMTA-0384 Auditory Alarms for Sleeping Crewmembers

If the alarm signal is intended to arouse sleeping crewmembers, then criterion a. of requirement HLS-HMTA-0381 Audio Display Sound Level shall be satisfied.

Rationale: To get the attention of the crew during sleep, alarms must have a signal-to-noise ratio of at least 15 dBA.

HLS-HMTA-0385 Visual and Audio Annunciations

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.

HLS-HMTA-0386 Set-Point Alerts

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.

HLS-HMTA-0387 Audio Annunciation Silencing

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.

HLS-HMTA-0388 Visual and Auditory Annunciation Failures

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.

HLS-HMTA-0389 Visual Alerts - Red

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.

HLS-HMTA-0390 Visual Alerts - Yellow

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.

HLS-HMTA-0391 Label Provision

The system shall provide labels 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.

HLS-HMTA-0392 Label Standardization

Labels should 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.

HLS-HMTA-0393 Label Display Requirements

Labels should meet the requirements of visual displays (section 10.3.3, Visual Display Devices, in NASA-STD-3001 Vol 2 Rev B), except font height (section 10.3.5.7, Label Font Height [V2 10066], 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.

HLS-HMTA-0394 Label Location

Labels should 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's missing their association or misidentifying items. This can slow down task performance and may cause errors.

HLS-HMTA-0395 Label Categories

Labels should 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.

HLS-HMTA-0396 Label Distinction

Labels should 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.

HLS-HMTA-0397 Label Font Height

Font height of 0.4 degrees or greater should 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.

HLS-HMTA-0399 Labeling of Hazardous Waste

Hazardous waste shall be labeled on the outermost containment barrier, and available as viewed from different sides of the container that the crew may regard it, to identify the hazard type and level contained (in accordance with JSC-26895).

Rationale: It is important for safe handling purposes that the waste container label be marked accurately and completely. When multiple types of hazardous waste are accumulated in a single hazardous waste container, the outermost container label is to indicate the highest level of toxicity contained.

HLS-HMTA-0400 Automated and Robotic System Provision

Automated and robotic systems shall be provided when crew cannot reliably, safely, or efficiently perform assigned tasks.

Rationale: Tasks that cannot be reliably, safely, or efficiently performed by the crew are to be identified. Requirements are to provide automated or robotic solutions that can perform these identified tasks. Tasks may include ones 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). The program will set requirements specifying appropriate capabilities to be provided for real-time monitoring of crew physiological or behavioral information to be fed back to the human or automated/robotic solution to facilitate crew readiness to perform (e.g., through intelligent alerting) or automated performance of identified tasks (e.g., in the event of assured indication of crew incapacitation).

HLS-HMTA-0398 Automated and Robotic System Design

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.

HLS-HMTA-0401 Robotic Control Stations - Common and Consistent

For a given robotic system, operator control stations should 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.

HLS-HMTA-0402 Automated and Robotic System Situational Awareness

Operator control stations for automated or robotic systems should provide the displays and interfaces needed for SA to perform tasks and manage the system.

Rationale: Operator control stations need to be designed such that the SA necessary for efficient and effective task performance is provided, and can be recovered if lost. Particular consideration should be paid to telerobotic software and hardware that may be required to operate robotic systems in the presence of communication transmission delays or when the operator and automation/robot are not co-located.

HLS-HMTA-0403 Automation Levels

The crew interfaces to automated and robotic systems should 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 result in increased crew performance (e.g., less errors) and lower workload, however, also result in poorer SA and loss of crew skills (Onnusch, Wicken, Li, & Manzey, 2013). This trade-off must be taken into consideration when designing automation and robotic systems. Automation is to be leveraged for tasks where human is unable to reliably, efficiently, or safely perform them. Task analysis in conjunction with functional allocation evaluations should determine the appropriate level of automation, and a trade analysis should be conducted to meet all the expected human-system performance.

HLS-HMTA-0404 Automation Level Status Indication

Operators of automated and robotic systems shall be provided with 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. 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. Evaluation of operator SA and mental models of automation while executing program-specific tasks should be included as part of the verification process.

HLS-HMTA-0405 Robotic System Status

Robotic assets should interact with the operating crew in accordance with section 10.1.6, System Interaction, in NASA-STD-3001, Vol 2 Rev B such that the operator can determine the asset health, status, and place in a procedural sequence and the ability of the robotic asset to comprehend and accept operator commands.

Rationale: The crew needs to have the constant ability to be aware of the status of a robotic asset to allow sufficient time for deliberate procedural modifications or emergency actions. Status information needs to include robotic asset health, past actions, confirming feedback to procedural modifications, and intended future actions.

HLS-HMTA-0406 Robotic System Arbitration

Robotic systems designed to have multiple operators should be able to accept the input from and arbitrate between multiple operators so as to perform safely and without degradation.

Rationale: Control of robotic systems may be performed by multiple groups that need to alternate control of the system within a given operating session, e.g., EVA and/or IVA crewmembers, lunar- /planetary-based operators, Earth-based operators. This transfer of control needs to (a) be accepted by these integrated systems, (b) occur in a safe manner such that it does not interfere with performance, and (c) occur without impeding upon the actions of the operators within or across groups. Design of controls should also allow the takeover of a robotic system from a primary operator by another operator/group in contingency or emergency situations.

HLS-HMTA-0407 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.

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.

HLS-HMTA-0408 Automation and Robotics Shut Down Capabilities

The crew shall be provided the ability to shut down predetermined 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. These systems will be identified in the Provider's Task Analysis. The crew is to remain in ultimate control of the vehicle at all times throughout a mission.

HLS-HMTA-0409 Automation and Robotics Override Capabilities

The crew shall be provided 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 crew is to remain in ultimate control of the vehicle at all times throughout a mission.

HLS-HMTA-0410 Crew Interfaces to Robotic Systems - Spatial Disorientation

Crew interfaces to robotic systems should account for different frames of reference between the operator and the robot to minimize spatial disorientation and allow the crew to accomplish their tasks within the required performance parameters.

Rationale: The frame of reference used for a human-robotic task is to be intuitive to the crew. Requirements are to accomplish this through specifying techniques such as matching of crew and robot frames of reference where appropriate or, at minimum, providing appropriate frame-of-reference labels and visual cues. In cases where the operator is to be immersed in the robot field of view, this would involve matching the robot frame of reference. Task efficiency (whether task time, accuracy, errors, or other relevant metrics) should not be degraded by lack of consideration of differing reference frames between robot and operator. For more information regarding this subject, see chapter 10, Crew Interfaces, of the HIDH.

HLS-HMTA-0411 Crew Interfaces to Robotic Systems - Frames of Reference

Crew interfaces to robotic systems should 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.

HLS-HMTA-0412 Reusability of Habitable Vehicles (sustainability)

For habitable vehicles that are planned to be re-used after being vacated in space, the following requirements shall be verified (previously "shoulds"): HMTA - 6041, 7011, 7014, 7015, 7051, 7052, 7053, 7055, 7059, 7058, 7060, 7061, 7062, 7063, 8010, 8011, 9034, 9035, 9036, 9037, 9040, 9041, 9042, 9043, 9044, 9045, 9046, 9048, 9049, 9050, 10005, 10006, 10007, 10009. (applicability TBC)

HLS-HMTA-0423 Medical Treatment Spatial Accommodation

The medical system should provide volume and surface area to treat a patient and allow access for the medical care provider and equipment.

Rationale: The size of a dedicated medical area or area capable of supporting medical activities depends on the number of crewmembers, mission duration, crew activities, and the likelihood that multiple crewmembers may become injured or ill enough to require simultaneous medical attention.

HLS-HMTA-0424 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.

> *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.*

HLS-HMTA-0429 Individual Medical Accessory Kit

The system shall accommodate mass and volume for crew-specific pharmaceuticals and medical supplies to support nominal and contingent medical and behavioral health needs.

C.1 Human Systems Verifications

Due to the sensitivity and specialization of human deep space flight systems, NASA is providing these draft verifications to the Appendix C tailored technical standards, above.

DVO-HLS-HMTA-0001 Design Using Human-Centered Task Analysis

Statement: Analysis - Task information shall be verified by analysis. An analysis shall be performed to identify human-related task activities and supporting information required for nominal and off-nominal operation in the applicable mission phases and environments. Guidance for completing a task analysis can be found in the NASA/TP-2014-218556 Human Integration Design Processes (HIDP).

Verification Success Criteria: Verification shall be considered successful when the analysis shows that human-related task activities and supporting information have been collected and analyzed for all nominal and off-nominal tasks in the applicable mission phases and environments.

DVO-HLS-HMTA-0002 Accommodate Physical Characteristics of Crew

Statement: Inspection, Analysis, Test - Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 4005, 4006, 4007, 4008, 4009, 4010, 4011, 4012 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances. Application of expected changes in body lengths, circumferences and posture shall be verified by analysis. The analysis shall include review of designs, drawings, flight-like mockups, and flight-like prototypes and extraction of measurements to compare against the data sets provided for changes in body lengths, circumferences and posture. The analysis shall consist of integrated task and worksite analysis performed on all crew functional areas. The analysis results shall be verified against the data sets provided for changes in body lengths, circumferences and posture by means of

population analytical methods. The verification shall be considered successful when the analysis shows that the measurements have been met and that the entire anthropometric range of crew as defined in the Physical Capabilities and Characteristics reference document is accommodated by the human-systems interfaces, including changes in body lengths, circumference and posture associated with reduced gravity.
Application of reach data to the design shall be verified by analysis and test. The analysis shall include review of designs, drawings, flight-like mockups, and flight-like prototypes and extraction of measurements to compare against the ranges provided in the Physical Capabilities and Characteristics reference document. The analysis shall consist of integrated task and worksite analysis performed on all crew functional areas. The test shall measure a human subject while physically interacting with a crew functional area within a flight or flight equivalent mockup. The analysis and test results shall be verified against the Physical Capabilities and Characteristics reference document by means of population analytical methods. The verification shall be considered successful when the analysis and test show that the measurements have been met and that the reach data of crew as defined in the Physical Capabilities and Characteristics reference document is accommodated by the human-systems interfaces.
The implementation of the body volume data to the design shall be verified by analysis. The analysis shall include a review of the design of all systems in which body volume data is necessary for design. The review shall clearly identify which system found the body volume data necessary for design and how the data was implemented. The verification shall be considered successful when the analysis show the system is capable of accommodating the expected body volumes of the crewmembers per the Physical Capabilities and Characteristics reference document.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0005 Perception and cognition capabilities
Statement: Inspection - Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 5005, 5006, 5007, 5008 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0010 Time and Performance
Statement: Analysis and Test - The ability to perform tasks in a timely and accurate manner shall be verified by analysis and test. A task analysis shall identify the representative tasks that should be tested for each mission scenario, along with the time and accuracy requirements for each of the tasks in that scenario. A Human-in-

the-Loop (HITL) test shall measure the task completion times and error rates for each task tested.

Verification Success Criteria: Verification shall be considered successful when the HITL results show that all tasks in each selected mission scenario have task completion times and error rates within the required limits shown in the task analysis.

DVO-HLS-HMTA-0011 Situational Awareness (SA)
Statement: Test - Accommodation of crew perception and cognition capabilities shall be verified by test. An integrated system, scenario-based HITL test shall be conducted of the critical mission tasks as identified in the DRD-HSR-001 Task Analysis. The test shall utilize hardware, software, and equipment in flight-like configuration to simulate the flight system to the extent necessary to verify that the crew interface design enables the crew to effectively and efficiently perform mission tasks with acceptable usability rating.

Verification Success Criteria: Based upon the task analyses for all mission phases, select human-computer-interaction tasks for situation awareness testing will be defined and scoped with applicable Program agreement. A human-computer-interaction task is defined as one which includes operation of the vehicle displays and controls. Each task is rated separately and has to meet the appropriate situation awareness demands of the task. Situation awareness for each of these tasks will be evaluated using a minimum of 10 test subjects who are adequately trained as operators of the system. The SAGAT tool (Endsley, 1988) will be used for the assessment of situation awareness, with acceptable SA scores for each task determined with applicable Program agreement.

DVO-HLS-HMTA-0012 Nominal Cognitive Workload
Statement: Analysis and Test - The workload rating for crew tasks shall be verified by analysis and test. The analysis shall consist of a task analysis to identify a list of NASA approved nominal tasks to be performed. The test shall consist of an evaluation by at least eight trained personnel who are crew or designated crew representatives performing each of the listed crew tasks in a flight-like simulator or mockup (i.e., a facility that is determined to be as close to flight like as is possible) and providing workload ratings on the Bedford Workload Scale. Tasks will be grouped so that related tasks will be performed concurrently and sequentially as expected during actual in-flight operations. When tasks are designed to be performed by multiple crewmembers, multiple personnel shall participate in the test and provide individual workload ratings. The evaluation period for each task shall span the duration of the task with personnel providing their ratings at the end of this period. During workload evaluation tests, personnel will maintain performance error rates and completion times commensurate with the performance requirements of the particular task. The verification shall be considered successful when the analysis in conjunction with the test results show that for representative nominal tasks identified in the analysis, at

least 6 of the 8 ratings are no greater than a rating of 3 on the Bedford workload scale, while up to 2 of the 8 ratings may exceed the rating of 3 (allowing workload ratings of 4, 5, or 6 on the Bedford workload scale). For any ratings of 4, 5, or 6, a consensus must be reached by all of the participants indicating that the workload is acceptable in order for verification to be considered successful.

Verification Success Criteria: Workload must be assessed repeatedly by highly trained individuals using a consistent methodology immediately following dynamic human-in-the-loop simulations of tasks. A key element of testing in a flight-like simulator or mockup is that the quality of error (i.e., consequences or penalties) is commensurate to the respective nominal, loss of mission, loss of crew, or loss of vehicle task or operational scenario. Workload should also be assessed in the design phase, prior to verification (including multi-dimensional tools such as the NASA-TLX), to ensure that the design or task does not induce unnecessary workload. The Bedford scale is appropriate for verification because it provides anchors for every rating, is familiar to the crew population, and provides a decision gate in which ratings above this gate are indicative of workload that is not satisfactory without a reduction in spare capacity. When using the Bedford scale, each subject must be briefed as to what each of the ratings on the scale mean, the task they are rating, the time period over which to make the rating, and the other tasks for which they need to judge their spare capacity. These items need to be consistent across subjects for each task. The Bedford scale is not linear and the underlying distribution is not predicted to be normal, thus calculation of a mean and median or the uses of parametric statistics are not appropriate. The Bedford scale allows for half ratings (e.g., 1.5), which is also allowed here, as long as the rating is less a 3 or less. A rating of 3.5 or higher is only acceptable for verification of this requirement if a consensus of all participants indicates that the workload is acceptable

DVO-HLS-HMTA-0013 Off-Nominal Cognitive Workload

Statement: Analysis and Test - The workload rating for crew tasks shall be verified by analysis and test. The analysis shall consist of a task analysis to identify a list of NASA approved off-nominal tasks to be performed. The test shall consist of an evaluation by at least eight trained personnel who are crew or designated crew representatives, and are representative of the crew population performing each of the listed crew tasks in a flight-like simulator or mockup (i.e., a facility that is determined to be as close to flight like as is possible) and providing workload ratings on the Bedford Workload Scale. Tasks will be grouped so that related tasks will be performed concurrently and sequentially as expected during actual in-flight operations. When tasks are designed to be performed by multiple crewmembers, multiple personnel shall participate in the test and provide individual workload ratings. The evaluation period for each task shall span the duration of the task with personnel providing their ratings at the end of this period. During workload evaluation tests, personnel will maintain performance error rates and completion times commensurate with the performance requirements of the particular task. The verification shall be considered successful when the analysis in conjunction with the test results show that for

representative off-nominal tasks identified in the analysis, all of the subjects provide a rating of 6 or less on the Bedford scale.

Verification Success Criteria: Workload must be assessed repeatedly by highly trained individuals using a consistent methodology immediately following dynamic human-in-the-loop simulations of tasks. A key element of testing in a flight-like simulator or mockup is that the quality of error (i.e., consequences or penalties) is commensurate to the respective nominal, loss of mission, loss of crew, or loss of vehicle task or operational scenario. Workload should also be assessed in the design phase, prior to verification (including multi-dimensional tools such as the NASA-TLX), to ensure that the design or task does not induce unnecessary workload. The Bedford scale is appropriate for verification because it provides anchors for every rating, is familiar to the crew population, and provides a decision gate in which ratings above this gate are indicative of workload that is not satisfactory without a reduction in spare capacity and a gate in which ratings above this gate are indicative of workload that is not tolerable for the task. When using the Bedford scale, each subject must be briefed as to what each of the ratings on the scale mean, the task they are rating, the time period over which to make the rating, and the other tasks for which they need to judge their spare capacity. These items need to be consistent across subjects for each task. The Bedford scale is not linear and the underlying distribution is not predicted to be normal, thus calculation of a mean and median or the uses of parametric statistics are not appropriate. This verification requires that every subject's raw score is a 6 or less on the Bedford scale. The Bedford scale allows for half ratings (e.g., 1.5), which is also allowed here, as long as the rating is a 6 or less. A rating of 6.5 or higher is not acceptable for verification of this requirement. A rating of 6 or less is acceptable for this verification because workload is expected to be higher under off-nominal than nominal conditions, but workload is still rated as tolerable for the task.

DVO-HLS-HMTA-0014 Shirt Sleeve Environment
Statement: Inspection - Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 6001, 6002, 6003, 6004, 6006, 6007, 6010, 6012, 6014, 6017, 6019, 6020, 6021, 6022, 6024, 6025 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0015 Trend Analysis of Environmental Data
Statement: Analysis and Test - Capability for each isolatable, habitable compartment to automatically record pressure, humidity, temperature, ppO2, and ppCO2 data shall be verified by test and analysis. The test shall be conducted with known values for pressure, humidity, temperature, ppO2, and ppCO2 being introduced into each isolatable, habitable compartment.

Verification Success Criteria: The analysis will consist of reviewing recordings from each compartment to ensure they are consistent with the known values introduced.

DVO-HLS-HMTA-0016 Inert Diluent Gas

Statement: Analysis and Test - The maintenance of partial pressure nitrogen shall be verified by analysis and test. The analysis shall include a review of the vehicle design and the measurements of partial pressure nitrogen during operation of an integrated vehicle system test.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that the vehicle can maintain the partial pressure nitrogen of the internal atmosphere within the ranges described in the requirement.

DVO-HLS-HMTA-0017 O2 Partial Pressure Range for Crew Exposure

Statement: Analysis and Test - The maintenance of oxygen partial pressure shall be verified by analysis supported by test. The analysis shall include a review of the vehicle design and the measurements of partial pressure oxygen during operation of an integrated vehicle system. At the vehicle or subsystem level, a test shall be performed using the vehicle's pressure control system in a controlled volume (i.e., pressure or vacuum chamber) with actual or simulated metabolic loads over the maximum mission duration to verify oxygen partial pressure control.

Verification Success Criteria: The verification shall be considered successful when the test and analysis data show that the vehicle can maintain the partial pressure oxygen of the internal atmosphere within the ranges described in the requirement.

DVO-HLS-HMTA-0018 Nominal Vehicle/Habitat Carbon Dioxide Levels

Statement: Analysis and Test - The maintenance of carbon dioxide partial pressure shall be verified by analysis supported by test. The analysis shall include a review of the vehicle design and the measurements of partial pressure carbon dioxide during operation of an integrated vehicle system. At the vehicle or subsystem level, a test shall be performed using the vehicle's pressure control system in a controlled volume (i.e., pressure or vacuum chamber) with actual or simulated metabolic loads over the maximum mission duration to verify carbon dioxide partial pressure control.

Verification Success Criteria: The verification shall be considered successful when the test and analysis data shows that the vehicle can maintain the partial pressure of carbon dioxide in the internal atmosphere within the limits specified.

DVO-HLS-HMTA-0019 Ventilation Rate

Statement: The capability to maintain a ventilation rate within the system shall be verified by analysis and test. The analysis shall include a fluid dynamics model of the interior habitable volume and shall be of sufficient fidelity to identify potential areas within the habitable volume with degraded air movement. The analysis shall include a plan to validate the model using data collected during the vehicles

acceptance/qualification testing. The analysis shall consider the ventilation rate only at a single, nominal setting for all fan speeds and diffusers. The test shall be of the flight hardware's response to commands in the flight vehicle.

Verification Success Criteria: The verification shall be considered successful when the analysis and test establish that two-thirds (66.7%) of the atmosphere velocities are between 4.57m/min (15ft/min) and 36.58 m/min (120 ft/min), no more than 5 percent of the velocities are less than 2.13 m/min (7 ft/min), and no more than one percent of the velocities are in excess of 60.96 m/min (200 ft/min) at a distance measured more than 0.15 m [6 inches]) from the vehicle walls during all mission phases, toxic cabin events, or when the crew is not inhabiting the vehicle.

DVO-HLS-HMTA-0020 Total Pressure Tolerance Range for Indefinite Crew Exposure
Statement: Analysis and Test - The maintenance of atmospheric pressure shall be verified by analysis supported by test. The analysis shall include a review of the vehicle design and the measurements of atmospheric pressure during operation of an integrated vehicle system under nominal conditions. At the vehicle or subsystem level, a test shall be performed using the vehicle's pressure control system in a controlled volume (i.e., pressure or vacuum chamber) with actual or simulated metabolic loads over the maximum mission duration to verify atmospheric pressure control.

Verification Success Criteria: The verification shall be considered successful when the test and analysis data show that the vehicle can maintain pressure of the internal atmosphere within the limits specified in Table 6.1.1.1-1 Physiological Total Pressure Limits for Crew Exposure.

DVO-HLS-HMTA-0021 Rate of Pressure Change
Statement: Analysis - The rate of total pressure change shall be verified by analysis. The analysis shall include a review of the vehicle design and an evaluation of the worst-case scenario for pressure change during nominal operations.

Verification Success Criteria: The verification shall be considered successful when the analysis indicates that the vehicle will not exceed the pressure change described in the requirement.

DVO-HLS-HMTA-0022 Relative Humidity
Statement: Analysis - The capability of the system to restrict human exposure to relative humidity levels shall be verified by analysis. The analysis shall be based on performance data collected on the Flight Environmental Control and Life Support System during subsystem or vehicle acceptance/qualification testing.

Verification Success Criteria: The verification shall be considered successful when the analysis demonstrates that the system can maintain the average relative humidity levels in the simulated vehicle configurations.

DVO-HLS-HMTA-0023 Comfort Zone

Statement: Analysis - Maintaining the atmospheric temperature within the specified range shall be verified by analysis. The analysis shall include a review of the system design, as well as a thermal model of the habitable volume based on the final flight configuration. The model shall be validated using test data collected from the vehicle during pre-delivery acceptance testing.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that the temperature can be maintained between 18 ºC (64.4 ºF) to 27 ºC (80.6 ºF) during all nominal flight operations, excluding suited operations.

DVO-HLS-HMTA-0025 Atmospheric Control

Statement: Test - Capability for crew to control atmospheric parameters and set-points for atmospheric pressure, partial pressure O2, temperature, humidity, and ventilation shall be verified by test. The test shall include human subjects in a high fidelity mockup of an integrated vehicle system using the provided controls to modify each atmospheric parameter. Measurements of actual atmospheric parameters shall be compared with set-points chosen by the test subject.

Verification Success Criteria: The verification shall be considered successful when the test shows that each atmospheric parameter can be controlled by the crew.

DVO-HLS-HMTA-0026 Atmospheric Data Recording

Statement: Analysis and Test - Capability for each isolatable, habitable compartment to automatically record pressure, humidity, temperature, ppO2, and ppCO2 data shall be verified by test and analysis. The test shall be conducted with known values for pressure, humidity, temperature, ppO2, and ppCO2 being introduced into each isolatable, habitable compartment.

Verification Success Criteria: The analysis will consist of reviewing recordings from each compartment to ensure they are consistent with the known values introduced.

DVO-HLS-HMTA-0027 Atmospheric Data Displaying

Statement: Demonstration - Capability for each isolatable, habitable compartment to display pressure, humidity, temperature, ppO2, and ppCO2 data shall be verified by demonstration.

Verification Success Criteria: The demonstration shall be considered successful when each isolatable, habitable compartment displays values for pressure, humidity, temperature, ppO2 and ppCO2 that are consistent with known values introduced.

DVO-HLS-HMTA-0028 Atmospheric Monitoring and Alerting

Statement: Demonstration - Onboard alerts of atmospheric parameters shall be verified by demonstration.

Verification Success Criteria: The demonstration shall take place in an integrated vehicle system. Each atmospheric parameter shall be set at contingency levels to produce alerts. The demonstration shall be considered successful when alerts are generated by out-of-limits parameters for atmospheric pressure, partial pressure O2, temperature, humidity, and ventilation.

DVO-HLS-HMTA-0414 Trace Constituent Monitoring and Alerting
Statement: Test - Trace Constituent Monitoring and Alerting shall be verified by test.

Verification Success Criteria: Verification shall be considered successful when the test demonstrates that the HLS system provides the capability to monitor trace volatile organic compounds and demonstrates that the HLS system provides the capability to alert both the ground crew and the in-flight crew whenever a monitored chemical parameter in the atmosphere approaches applicable limits during crewed operations.

DVO-HLS-HMTA-0029 Combustion Monitoring and Alerting
Statement: Test - The ability of the system to measure, display, transmit, and alert crew and ground personnel of the atmospheric concentration of toxic combustion products in the required ranges shall be verified by test. The test shall show that the atmospheric monitoring instruments correctly and accurately measure the atmospheric concentration of toxic combustion products in the required ranges.

Verification Success Criteria: The verification shall be considered successful when the test shows a real time capability for the measurement, display, transmitting, and alerting of atmospheric concentrations of the specified toxic combustion products over the specified ranges with the required accuracy and resolution.

DVO-HLS-HMTA-0030 Contamination Monitoring and Alerting
Verification: The limit of particulate in the internal atmosphere shall be verified by analysis. The analysis shall include a review of the vehicle design.

Verification Rationale: The verification shall be considered successful when the analysis shows that the 24-hour average particulate concentration within the vehicle remains below 0.2 mg/m3 for particles ranging from 0.5 micron to 100 microns in aerodynamic diameter and generated at a rate of 0.09 mg/person-minute.

DVO-HLS-HMTA-0031 Decompression Sickness (DCS) Risk Mitigation
Statement: Test - Maintaining the internal pressure and gaseous oxygen concentration for the required time durations for denitrogenation shall be verified by test. The test shall adjust the pressures and concentrations as defined in HS6091, table Prebreathe Durations for Contingency EVA and table Prebreathe Durations for Nonrecoverable Cabin Depress in an integrated configuration of the vehicle including

the suit. The verification shall be considered successful when the test shows that the vehicle can vary pressures and gas concentrations per the denitrogenation protocol. And Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 6008, 6009 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0032 Decompression Sickness Treatment Capability
Statement: Analysis - Decompression Sickness (DCS) treatment capabilities shall be verified by analysis. The analysis shall evaluate the system's ability to provide a pressure of 156.5 kPa (22.7 psia) (1,174 mmHg) to a DCS affected crewmember via a combination of vehicle and suit pressures. The verification shall be considered successful when the analysis shows that the specified pressure can be achieved by crewmembers within 2 hours of a DCS event and maintained for 6 hours.

Verification Success Criteria: The 2-hour limit includes the time it takes for the crew to don their suits, assuming they are not suited at the time the need for treatment is realized.

DVO-HLS-HMTA-0033 Potable Water
Statement: Inspection - Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 6026, 6027, 6105, 6029, 6030, 6031, 6032, 6033, 6034, 6035, 6036, 6037, 6038, 6039, 6040, 6043, 6045 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0034 Potable Water Physiochemical Limits
Statement: Test - Physiochemical water quality shall be verified by test. The test shall include a pre-flight evaluation of a fully integrated flight-equivalent water system for a length of time that encompasses the expected mission duration. Samples shall be collected from all points of crew consumption or contact to verify compliance. Samples shall be analyzed using standard laboratory techniques described in Standard Methods for Examination of Water & Wastewater, American Public Health Association or approved alternate methodology that will provide equivalent data. Analytical methods that are not listed in Standard Methods for Examination of Water and Wastewater must be approved by the JSC water quality group prior to use.

Verification Success Criteria: The verification shall be considered successful when test data demonstrate that the [system/vehicle] potable water system provides water

at or below the appropriate maximum concentrations listed in JSC 63414, Spacecraft Water Exposure Guidelines (SWEGs) or other applicable standard.

DVO-HLS-HMTA-0035 Potable Water Microbial Limits

Statement: Test - Microbiological water quality shall be verified by test. The test shall include evaluation of a fully integrated flight-equivalent water system for a length of time equal to the longest period expected between preflight preparation of potable water and postflight crew recovery. Samples shall be collected from all locations throughout the water system to which the crew may be exposed to verify compliance. These tests shall be conducted using standard laboratory techniques described in Standard Methods for Examination of Water & Wastewater, American Public Health Association or alternate approved methodology that will provide comparable data. Analytical methods that are not listed in Standard Methods for Examination of Water & Wastewater must be approved by the JSC microbiology group prior to use.

Verification Success Criteria: The verification shall be considered successful when test data are compliant with Table 13 Potable Water Microbiological Limits.

DVO-HLS-HMTA-0040 Water Treatment Chemicals and Residual Biocides

Statement: Test - This requirement shall be verified by test. The test shall include pre-flight evaluation of a fully integrated flight-equivalent water system for a length of time that encompasses the expected mission duration and includes all treatment chemicals and residual biocides. Samples shall be collected from all points of crew consumption or contact to verify compliance. Samples shall be analyzed using standard laboratory techniques described in Standard Methods for Examination of Water & Wastewater, American Public Health Association or approved alternate methodology that will provide equivalent data. Analytical methods that are not listed in Standard Methods for Examination of Water and Wastewater must be approved by the JSC water quality group prior to use.

Verification Success Criteria: The verification shall be considered successful when test data demonstrate that the treatment chemicals and residual biocides used in the potable water system are below levels that could adversely affect crew health.

DVO-HLS-HMTA-0036 Drinking Water Quantity

Statement: Analysis - The provisioning of the specified quantity of potable water shall be verified by analysis. The analysis shall determine the amount of potable water stowage on the vehicle for the design reference mission utilizing maximum crew size and maximum mission duration.

Verification Success Criteria: The verification shall be considered successful when the analysis shows sufficient volume and mass capacity for stowage of 2.5 L (84.5 fl oz) of potable water per crewmember per mission day for drinking in addition to other potable water quantity requirements.

DVO-HLS-HMTA-0038 Water Dispensing Rate
Statement: Test - The potable water flow rate shall be verified by test.

Verification Success Criteria: The verification shall be considered successful when the analysis demonstrates that the system can maintain the average relative humidity levels in the simulated vehicle configurations.

DVO-HLS-HMTA-0037 Water Dispensing Increments
Statement: Test - The capability of the vehicle to dispense water in 15-mL (0.51-fl oz) increments (+/-10% or 5 mL [0.17 fl oz], whichever is greater) between the quantities of 30 mL (1.01 fl oz) and 240 mL (8.12 fl oz) shall be verified by test. Testing shall include dispensing of water in 15-mL (0.51-fl oz) increments, starting at 30 mL (1.01 fl oz).

Verification Success Criteria: The verification shall be considered successful when the test shows that the water system can dispense water in 15-mL (0.51-fl oz) increments (+/-10% or 5 mL [0.17 fl oz], whichever is greater) between the quantities of 30 mL (1.01 fl oz) and 240 mL (8.12 fl oz).

DVO-HLS-HMTA-0039 Water Temperature
Statement: Test - The capability of the vehicle to dispense hot water shall be verified by test.

DVO-HLS-HMTA-0041 Toxic Hazard Level Three
Statement: Analysis - Use of chemicals that are Toxic Hazard Level Three or below in the habitable volume of the system shall be verified by analysis. The analysis shall include a review of the materials and chemicals selected for spacecraft construction and their use in the operation of the vehicle.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that only Toxic Hazard Level 3 or lower chemicals are used in the habitable volume of the vehicle and that no decomposition products of the chemicals will be a Toxicological Hazard Level Four.

DVO-HLS-HMTA-0042 Toxic Hazard Level Four
Statement: Analysis - Preventing Toxic Hazard Level Four chemicals from entering the habitable volume of the spacecraft shall be verified by analysis. The analysis shall include a review of the vehicle design and operational procedures.

Verification Success Criteria: The verification shall be considered successful when the analysis shows adequate controls are in place to prevent Toxic Hazard Level Four chemicals from entering the habitable volume of the spacecraft.

DVO-HLS-HMTA-0043 Chemical Decomposition

Statement: Inspection and Analysis - The prevention of chemical decomposition into hazardous compounds in the habitable volume shall be verified by analysis and inspection. The analysis shall identify chemicals that will be exposed to or have the potential to be introduced into the habitable volume and the likely chemical interactions with the environment. The inspection shall include a review of Program Safety Review Panel approval documentation.

Verification Success Criteria: The verification shall be considered successful when the analysis and inspection show that no chemicals have been used in the system's design that can be broken down or converted into compounds that threaten crew health and have the potential to be introduced into the habitable volume.

DVO-HLS-HMTA-0044 Atmosphere Contamination Limit – Airborne Contaminants

Statement: Test and Analysis - Control of gaseous pollutants in the habitable volume shall be verified by test and analysis. The test, conducted according to SSP 41172, Qualification and Acceptance Environmental Test Requirements, shall be used to determine the integrated vehicle equipment off-gassing load. The analysis shall evaluate the vehicle's active control of the concentration of individual trace chemical contaminants introduced into the cabin. The analysis shall include contributions from system chemicals, equipment off-gassing, and crew metabolic loads.

Verification Success Criteria: The verification shall be considered successful when the test and analysis shows the total toxicity hazard index is <1.0 unit during crew habitation. The total T value shall be calculated using 7-day SMACs and shall include contributions from system chemical, equipment off-gassing, and crew metabolic loads.

DVO-HLS-HMTA-0046 Particulate Matter

Statement: Analysis - The ability of the system to limit the amount of particulate matter in the habitable volume shall be verified by analysis. The analysis shall include a review of the vehicle design to ensure that there is adequate airflow and filtration to control particulate matter in the habitable volume.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that the system controls total dust to <3 mg/m3 with a crew generation rate of 1.33 mg/person-minute, and the respirable fraction of the total dust <2.5 μm in aerodynamic diameter to <1 mg/m^3 with a crew generation rate of 0.006 mg/person-minute.

DVO-HLS-HMTA-0047 Lunar Dust Contamination

Statement: Analysis - The limit of lunar dust in the internal atmosphere shall be verified by analysis and test. The analysis shall include a review of the vehicle design and testing of the Atmosphere Revitalization System (ARS).

Verification Success Criteria: The verification shall be considered successful when the analysis and tests show that the particulate contamination of less than 10 µm in size in the habitable atmosphere below a time-weighted average of 1.6 mg/m^3 during intermittent daily exposure periods that may persist up to 30 days in duration.

DVO-HLS-HMTA-0048 Design for Cleanliness
Statement: Inspection - Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 6056, 6057, 6058, 6059, 6060, 6061, 6063, 7079, 7080, 7081, 7083, and 7019 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0049 Surface Cleanability
Statement: Analysis - Surface cleanability shall be verified by analysis. The analysis shall include a review of the interior surfaces of the spacecraft.

Verification Success Criteria: The verification shall be considered successful when the analysis confirms that interior surfaces of the vehicle are made from materials that minimize microbial growth and are compatible with in-flight cleaning and disinfection.

DVO-HLS-HMTA-0050 Condensation Limitation
Statement: Analysis - The condensation persistence on surfaces shall be verified by analysis. The analysis shall consider crew induced metabolic loads for a Standard Mission Day With Exercise. The analysis shall include a thermal analysis to determine expected water on internal surfaces.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that condensation persistence is limited to 1 hour a day on surfaces within the internal volume during the mission.

DVO-HLS-HMTA-0051 Microbial Air Contamination Prevention
Statement: Analysis - The limitation of microbial contaminants in the internal atmosphere shall be verified by analysis. The analysis shall include a review of the vehicle design to ensure adequate airflow and filtration is in place.

Verification Success Criteria: The verification shall be considered successful when the analysis shows continuous air flow within the vehicle that has been cleaned to have at least 99.97% of airborne particles 0.3 micrometers (µm) and larger in diameter/size removed.

DVO-HLS-HMTA-0052 Cross-Contamination

Statement: Inspection and Analysis - Functional cross-contamination control shall be verified through analysis and inspection. A task analysis shall be performed at the specified areas. The designated locations of the food preparation, body waste management, and personal hygiene areas will be evaluated to verify that the system allows for activities in these areas while limiting cross-contamination. CAD 3-D models of the vehicle layout showing the distance between these areas will be inspected. The verification shall be considered successful when analysis and inspection show that the system is capable of controlling cross-contamination between food preparation and body waste management and food preparation and personal hygiene areas.

Verification Success Criteria: An analysis is needed for the verification in order to review the task analysis, and to ensure that the provided design solution meets the needs identified in that task analysis.

DVO-HLS-HMTA-0053 Availability of Environmental Hazards Information

Statement: Inspection - Availability of Environmental Hazards Information shall be verified by demonstration.

Verification Success Criteria: Verification shall be considered successful when the inspection shows that the crew has environmental hazards information available under simulated flight conditions.

DVO-HLS-HMTA-0054 Contamination Cleanup

Statement: Inspection and Analysis - The ability of the system to remove or reduce contamination from the habitable volume shall be verified by inspection and analysis. NASA shall do an inspection of the task analysis performed during the design phase to ensure that all scenarios for contamination are addressed by the design solution. An inspection of contamination control supplies shall determine whether adequate contamination control has been provided. The verification shall be considered successful when inspection shows that an adequate task analysis was performed and a comprehensive set of hardware is provided to address the identified contamination scenarios.

Verification Success Criteria: Due diligence in the identification of all possible contamination scenarios is essential to meeting this requirement. NASA spaceflight experience with dealing with onboard contamination contingencies must be incorporated. Exhaustive efforts to identify all scenarios will facilitate identification and use of proper hardware to address these scenarios.

DVO-HLS-HMTA-0055 Accessibility for Cleaning

Statement: Analysis - The ability of the crew to access areas for cleaning will be verified via analysis. NASA shall do an inspection of the task analysis performed

during the design phase to ensure that all scenarios for cleaning are addressed by the design solutions.

Objective: No further rationale is required

DVO-HLS-HMTA-0056 Particulate Control
Statement: Analysis - The ability of the system for access, inspection and removal of particulate shall be verified by analysis. NASA shall do an inspection of the task analysis performed during the design phase to ensure that the crew can access the appropriate areas for inspection and particulate removal.

DVO-HLS-HMTA-0057 Cleaning Materials
Statement: Analysis and Demonstration - The ability of the system, such than surface cleaning materials are effective, safe for human use, and compatible with the water reclamation, air revitalization, and water management systems shall be verified via test (or demonstration) and analysis. Effectiveness of the surface cleaning materials shall be verified by test (or demonstration). This test/demonstration will be considered successful when the surface cleaning materials are shown to perform as described in this standard rationale. To verify that the surface cleaning materials are safe for human use and compatible with the water reclamation, air revitalization, and water management systems, the analysis shall include a review of the materials and chemicals selected. The verification shall be considered successful when the analysis shows that the selected cleaning materials are Toxic Level X or lower and are compatible with the spacecraft systems operations.

Verification Success Criteria: The test/demonstration will be considered successful when the surface cleaning materials are shown to perform as described in this standard rationale. The verification shall be considered successful when the analysis shows that the selected cleaning materials are Toxic Level X or lower and are compatible with the spacecraft systems operations.

DVO-HLS-HMTA-0058 Hygiene Equipment Cleanliness
Statement: Analysis and Test - The provision of an environmentally compatible cleaning and sanitization method for personal hygiene facilities and equipment shall be verified by test and analysis. The test shall be considered successful when hygiene equipment and facility surfaces can be visibly cleaned, and sanitized to acceptable levels.

Verification Success Criteria: The analysis shall be considered successful when it shows that the method is compatible with human health and with environmental control and life support (ECLS) systems on the vehicles.

DVO-HLS-HMTA-0059 Sustained Translational Acceleration Limits
Statement: Analysis and Test - The crew exposure to sustained linear acceleration shall be verified by analysis that is supported by test. Analysis shall use a certified

simulation to identify all flight phase scenarios, as well as Monte Carlo studies with dispersed Guidance, Navigation, and Control (GN&C), vehicle and environmental factors as appropriate. Tests shall be used to validate the model using data obtained from nominal flight tests, and/or other available flight and ground-based tests. The test data will provide continuous acceleration measures in order to compute the total linear acceleration that would be experienced by the crew directly by translation and indirectly by off-axis rotation (i.e., centrifugal force). Such testing will require on-board acquisition (or sampling) of 3D linear and 3D rotational acceleration (along and around the x, y, and z axes) on a millisecond timescale.

Verification Success Criteria: The verification shall be considered successful when the analyses indicate with acceptable confidence and acceptable consumer risk that linear acceleration, accumulated for durations of 500 ms, or more are no greater than the limits depicted in Figures 2, 3, 4, 5, 6, and 7.

DVO-HLS-HMTA-0060 Rotational Velocity

Statement: Analysis and Test - The crew exposure to rotational velocities shall be verified by analysis that is supported by test. The test shall consist of flight tests. Nominal flight tests will provide acceleration measurements to evaluate vehicle rotational velocity. Testing will require continuous on-board acquisition (or sampling) of 3D rotational velocity at an acceptable sampling rate. The analysis shall use a certified simulation to verify all nominal flight phase scenarios, as well as Monte Carlo studies with dispersed Guidance, Navigation, and Control (GN&C), and vehicle and environmental factors.

Verification Success Criteria: The verification shall be considered successful when the analyses indicate with acceptable confidence and acceptable consumer risk that the rotational velocities, accumulated for durations of 500 ms or more, are no greater than the limits depicted in Figure 8.

DVO-HLS-HMTA-0061 Sustained Rotational Acceleration Due to Cross-Coupled Rotation

Statement: Analysis and Test - The crew exposure to sustained rotational acceleration caused by cross-coupled rotations shall be verified by analysis that is supported by test. The analysis shall use a certified simulation to verify all nominal flight phase scenarios. The simulation shall use rotational velocity measurements collected from flight tests in order to evaluate vehicle angular acceleration caused by cross-coupled rotation. Testing will require continuous on-board acquisition (or sampling) of 3D rotational velocities in an orthogonal coordinate frame at an acceptable rate. Rotational velocities shall be decomposed into their orthogonal principal components before computing accelerations due to their respective cross-product velocity terms. The analysis shall use a certified simulation to verify all nominal flight phase scenarios, as well as Monte Carlo studies with dispersed Guidance, Navigation, and Control (GN&C), and vehicle and environmental factors.

Verification Success Criteria: The verification shall be considered successful when the analysis indicates with acceptable confidence and acceptable consumer risk that the sustained rotational acceleration in any of the velocity principal-component axes is no greater than 2 rad/s2.

DVO-HLS-HMTA-0062 Transient Translational Acceleration
Statement: Analysis and Test - The risk of injury to crewmembers caused by accelerations during dynamic mission phases shall be verified by analysis supported by test. Analysis shall use a certified simulation to identify all flight phase scenarios, as well as bounding Monte Carlo studies with dispersed GN&C, vehicle and environmental factors, as appropriate, to determine likelihood of occurrence. Tests shall be used to validate the model using data obtained from nominal flight tests, and/or other available flight and ground-based tests.

Verification Success Criteria: The verification shall be considered successful when the analysis indicates with acceptable confidence with acceptable consumer risk that the vehicle meets the limits specified in Table 14.

DVO-HLS-HMTA-0415 Transient Rotational Acceleration
Statement: Analysis and Test - The crew exposure to transient (≤0.5 seconds) rotational accelerations shall be verified by analysis supported by test. Analysis shall use a certified simulation to identify all flight phase scenarios, as well as Monte Carlo studies with dispersed GN&C, vehicle and environmental factors, when appropriate. Tests shall be used to validate the model using data obtained from nominal flight tests, and/or other available flight and ground-based tests.

Verification Success Criteria: The verification shall be considered successful when the analysis indicates with acceptable confidence with acceptable consumer risk that the transient rotational accelerations in yaw, pitch, or roll to which the crew is exposed do not exceed 2,200 rad/s2 for nominal and 3,800 rad/s2 for off-nominal cases when scaled for each crewmember size from the 50th percentile male.

DVO-HLS-HMTA-0063 Acceleration Rate of Change
Statement: Analysis and Test - The crew exposure to translational acceleration rates of change (i.e., jerk) shall be verified by analysis supported by test. Analysis shall use a certified simulation to identify all flight phase scenarios, as well as Monte Carlo studies with dispersed GN&C, vehicle and environmental factors, when appropriate. Tests shall be used to validate the model using data obtained from nominal flight tests, and/or other available flight and ground-based tests.

Verification Success Criteria: The verification shall be considered successful when the analysis indicates with acceptable confidence and with acceptable consumer risk that the sustained translational acceleration rates of change do not exceed 500g/s.

DVO-HLS-HMTA-0065 Vehicle Acceleration Monitoring and Analysis
Statement: Analysis and Demonstration - Vehicle Acceleration Monitoring and Analysis shall be verified by demonstration and analysis.

DVO-HLS-HMTA-0066 Hang Time Limit
Statement: Demonstration and Test - Hang Time Limit shall be verified by demonstration/test.

DVO-HLS-HMTA-0067 Acoustic Limits
Statement: Inspection - Inspection of compliance with requirements HLS-HMTA-0069, HLS-HMTA-0070, HLS-HMTA-0071, HLS-HMTA-0072, HLS-HMTA-0073, HLS-HMTA-0074, HLS-HMTA-0075, HLS-HMTA-0076, HLS-HMTA-0077, HLS-LHMTA-0078, HLS-HMTA-0079, HLS-HMTA-0080, HLS-HMTA-0081, and HLS-HMTA-0082 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0068 Intermittent Noise Limits
Statement: Analysis and Test - The intermittent noise shall be verified by test and analysis. Sound Pressure Level (SPL) measurements shall be made of the actual flight hardware (each serialized unit) in its flight configuration with closeouts installed. Hardware shall be operated across the expected range of settings, including settings corresponding to the expected highest noise levels. Measurements shall be made using a Type 1 integrating-averaging sound level meter for each item that operates (produces noise) intermittently. The maximum A-weighted overall SPL (LAmax) shall be measured with a fast (125 ms) exponentially-weighted time-averaged response. Analysis shall be used to include any measured acoustical effects of the hardware installation configuration or to combine measured sound pressure levels of hardware items that must be operated simultaneously when these factors are not accurately represented in field tests. If the noise generated by a specific hardware item is influenced by the operation of another hardware item, then these hardware items shall be tested together. Analysis shall also be used to calculate the maximum operational duration to include the total time during any 24-hour period that the hardware item operates above the continuous noise limits given in HLS-HMTA-0076, Table 20: Octave Band SPL Limits for Continuous Noise.

Objective: Serialized units must be verified individually because different units produced from the same design can generate significantly different noise levels. Noise attenuation gained by the use of hearing protection is not to be considered toward the compliance of this requirement because hearing protection may not always be worn. Intermediate testing and analysis should be performed and reviewed by NASA to ensure confidence that compliance with this requirement will be met and to preclude

late impacts to cost, schedule, and hardware. Prototype or qualification units should be tested prior to manufacture of the actual flight equipment.

Verification Success Criteria: This verification shall be considered successful when the test (and any performed simulations) indicates that the maximum noise level for the duration of intermittent operation, measured 0.6 m from the loudest point on the hardware surface or at the center of the vehicle if the noise source is external to the vehicle, meets the level and duration limits specified in HLS-HMTA-0068, Table:19: Intermittent Noise A-Weighted SPL and Corresponding Operational Duration Limits for any 24-Hour Period (measured at 0.6-m distance from the source).

DVO-HLS-HMTA-0069 Cabin Depressurization Valve Hazardous Noise Limit
Statement: Analysis and Test - The cabin depressurization valve hazardous noise limit shall be verified by test and analysis. The test and analysis shall consist of estimating the maximum sound level at the crewmember's ear by combining significant noise sources from estimates of valve noise and including acoustic insertion losses of protective devices. The pressure-relief valve noise shall be determined by test. If allowed, the effectiveness of hearing protection, headsets, and helmets shall be determined by test.

Verification Success Criteria: The verification shall be considered successful when tests and analysis indicate that, during pressure relief valve operations, the maximum level predicted at the crewmember's ears is 105 dBA or less.

DVO-HLS-HMTA-0070 Cabin Depressurization Valve Noise Dose Limits
Statement: Analysis and Test - The cabin depressurization valve - noise dose limit shall be verified by test and analysis. The test and analysis shall consist of estimating the noise level as a function of time at the crewmember's ear by combining significant noise sources from estimates of valve noise and including acoustic insertion losses of protective devices. The pressure-relief valve noise shall be determined by test. If allowed, the effectiveness of hearing protection, headsets, and helmets shall be determined by test. Noise levels for the balance of the 24-hour calculation period shall be assumed to be 65 dBA.

Verification Success Criteria: The verification shall be considered successful when the analysis indicates with acceptable confidence and acceptable consumer risk that the sustained rotational acceleration in any of the velocity principal-component axes is no greater than 2 rad/s2.

DVO-HLS-HMTA-0071 Ascent, Landing and Abort Noise Exposure Limits
Statement: Inspection, Analysis and Test - The noise dose limits for ascent, landing, and abort shall be verified by test and analysis. The noise level as a function of time for the launch, entry, and ascent abort measured at the crewmember’s ears shall be determined by flight-testing. The test and analysis shall consist of estimating the noise level as a function of time at the crewmember’s ear by combining significant noise

sources from estimates of rocket noise and external flow boundary layer noise, and including acoustic insertion losses of acoustic isolation and protective devices. The rocket noise should be determined by test. Acoustic insertion losses of the pressure shell and other materials shall be determined by test. The effectiveness of hearing protection, headsets, and helmets shall be determined by test. Noise levels for the balance of the 24-hour calculation period shall be assumed to be 65 dBA.

Verification Success Criteria: The verification shall be considered successful when tests and analysis indicate that the 24-hour noise dose associated with ascent, landing, and ascent abort predicted at the crewmember's ears is 100% or less.

DVO-HLS-HMTA-0072 Sound Level Ceiling Limit for Ascent and Landing
Statement: Analysis and Test - The hazardous noise limit for ascent and landing shall be verified by test and analysis. The maximum noise level measured at the crewmember's ears shall be determined by flight-testing. The test and analysis shall consist of estimating the maximum sound level at the crewmember's ear by combining significant noise sources from estimates of rocket noise and external flow boundary layer noise and including acoustic insertion losses of acoustic isolation and protective devices. The rocket noise should be determined by test. Acoustic insertion losses of the pressure shell and other materials shall be determined by test. The effectiveness of hearing protection, headsets, and helmets shall be determined by test. The verification shall be considered successful when the tests and analysis indicate that the maximum level predicted at the crewmember's ears is 105 dBA or less during ascent and landing.

Verification Success Criteria: The verification shall be considered successful when the tests and analysis indicate that the maximum level predicted at the crewmember's ears is 105 dBA or less during ascent and landing.

DVO-HLS-HMTA-0073 Sound Level Ceiling Limit for Aborts
Statement: Analysis and Test - The hazardous noise limit during abort shall be verified by test and analysis. The maximum noise level measured at the crewmember's ears shall be determined by flight-testing. The test and analysis shall consist of estimating the maximum sound level at the crewmember's ear by combining significant noise sources from estimates of rocket noise and external flow boundary layer noise and including acoustic insertion losses of acoustic isolation and protective devices. The rocket noise should be determined by test. Acoustic insertion losses of the pressure shell and other materials shall be determined by test. The effectiveness of hearing protection, headsets, and helmets shall be determined by test.

Verification Success Criteria: The verification shall be considered successful when the tests and analysis indicate that the maximum level predicted at the crewmember's ears is 115 dBA or less during launch abort.

DVO-HLS-HMTA-0074 Ascent, Landing and Abort and Other Burn Impulse Noise Limits

Statement: Analysis and Test - The impulse noise limit for ascent and landing shall be verified by test and analysis. The impulse noise level measured at the crewmember's ears shall be determined by flight-testing. The test and analysis shall consist of estimating the impulse noise level at the crewmember's ear by combining significant noise sources and including acoustic insertion losses of acoustic isolation and protective devices. The ignition noise should be determined by test. Acoustic insertion losses of the pressure shell and other materials shall be determined by test. The effectiveness of hearing protection, headsets, and helmets shall be determined by test. Peak-hold sound pressure level measurements shall be made using a Type 1 sound level meter. The frequency response of the sound level meter shall extend to at least 6 Hz at its lower limit. Formal verification is not required for equipment with impulse noises that have peak overall SPLs of less than 110 dB.

Verification Success Criteria: The verification shall be considered successful when the test and analysis results indicate that the peak overall sound pressure level predicted at the crewmember’s ears is less than 140 dB.

DVO-HLS-HMTA-0075 Hazardous Noise Limits for All Phases Except Ascent, Landing and Abort and Other Lander Burns

Statement: Analysis and Test - The hazardous noise limit shall be verified by test and analysis. The SPL measurements for this verification shall be made using the actual flight equipment (each serialized unit) including GFE, portable equipment, payloads, and cargo. Sound Pressure Level (SPL) measurements shall be made using a Type 1 integrating-averaging sound level meter for each item of equipment and during all anticipated activities including maintenance. The maximum A-weighted overall SPL (LAmax) with a fast (125 ms) exponentially weighted time averaged response shall be measured. Analysis shall be used to include the effects of reflections, standing waves, or reverberation or to combine measured sound pressure levels of hardware items that will be operated simultaneously when these factors are not accurately represented in the field test. If the noise generated by a specific hardware item is influenced by the operation of another hardware item then these hardware items shall be tested together. The verification shall be considered successful when field testing (and any performed simulations) indicates that the maximum level, measured at any location (no closer than 8 cm to surfaces) within the habitable volume and at any maintenance operation head location, is below 85 dBA (LAmax) for communications and 95 dBA for alarms for any combination of individual hardware items that may occur simultaneously.

Verification Success Criteria: Serialized units must be verified individually because different units produced from the same design can generate significantly different noise levels. Noise attenuation gained by the use of hearing protection is not to be considered toward the compliance of this requirement because hearing protection may not always be worn. Intermediate testing and analysis should be performed and reviewed by NASA to ensure confidence that compliance with this requirement will be met and to preclude late impacts to cost, schedule, and hardware.

DVO-HLS-HMTA-0076 Continuous Noise Limits

Statement: Test - The continuous noise limit shall be verified by test. The measurements shall be made within the vehicle in the flight configuration with integrated GFE, stowage, vehicle installations, and closeouts installed. Continuous noise generated by portable equipment, payloads, and cargo shall be assumed to be equivalent to NC-46 and shall be added to the verification measurements. Hardware shall be operated across the expected range of operational settings (including settings corresponding to the expected highest noise levels). Equivalent-continuous sound level, Leq, measurements shall be made within each octave band with center frequencies ranging from 63 Hz to 16 kHz, using a Type 1 integrating-averaging sound level meter with a 20-second averaging time. Measurements shall be made at expected work and sleep station head locations, as well as throughout the habitable volume, to determine a spatial average of other potential crew head locations. Measurement locations shall be no closer than 30 cm from each other and no closer than 8 cm from any surface. The spatial average shall be based on incoherent sound power addition (i.e., average of pressure-squared values). The verification shall be considered successful when field testing indicates that

a) the measured Leq at each expected work and sleep station head location and the estimated center of the habitable volume do not exceed the levels within each octave band indicated in Table 20, Octave Band SPL Limits for Continuous Noise,
b) the spatially-averaged SPLs (average of pressure-squared values) throughout the habitable volume do not exceed the levels given in Table 20, Octave Band SPL Limits for Continuous Noise. The spatial average shall include locations used in 1) above, and a sufficient number of additional locations, to achieve a ± 2 dB 90% confidence interval within each octave band from 250 Hz to 16 kHz, and
c) no octave band sound pressure level measured at any location or at the maximum level location (i.e., the location of the maximum A-weighted overall sound pressure level found with a handheld sound level meter) within the entire habitable volume is more than 4 dB above the levels specified in Table 20, Octave Band SPL Limits for Continuous Noise at the corresponding octave-band center frequency.

Verification Success Criteria: Lower nominal settings of major hardware components shall also be tested and documented because expected maximum operational settings may not correspond to the highest noise levels. Noise attenuation gained by the use of hearing protection is not to be considered toward the compliance of this requirement because hearing protection may not always be worn. Intermediate testing and analysis should be performed and reviewed by NASA to ensure confidence that compliance with this requirement will be met and to preclude late impacts to cost, schedule, and hardware.

DVO-HLS-HMTA-0077 Alarm Maximum Sound Level Limit

Statement: Test - The maximum alarm SPL shall be verified by test. The SPL measurements for this verification shall be made using the actual flight equipment (each serialized unit), installed in the actual flight vehicle in its final configuration with all closeouts installed. SPL measurements shall be made using a Type 1 integrating-averaging sound level meter. The maximum A-weighted SPL (LAmax) with a fast (125 ms) exponentially weighted time averaged response shall be measured. The verification shall be considered successful when field testing indicates that the maximum level, measured at any location (no closer than 8 cm to surfaces) within the habitable volume is below 95 dBA for alarms.

Objective: Serialized units must be verified individually because of reverberation effects inside the vehicle. Noise attenuation gained by the use of hearing protection is not to be considered toward the compliance of this requirement because hearing protection may not always be worn. Intermediate testing and analysis should be performed and reviewed by NASA to ensure confidence that compliance with this requirement will be met and to preclude late impacts to cost, schedule, and hardware.

DVO-HLS-HMTA-0078 Annoyance Noise Limits for Crew Sleep

Statement: Test - The annoyance noise limit shall be verified by test. The measurements shall be made within the vehicle in the flight configuration with integrated Government Furnished Equipment (GFE), portable equipment, payloads, and cargo installed. Hardware shall be operated at settings that occur during crew rest periods. Measurements shall be made at expected head locations during sleep using a Type 1 integrating-averaging sound level meter. Measurement locations shall be no closer than 8 cm from any surface. Peak-hold sound pressure level (impulse noise) and A-weighted Overall SPL measurements shall be made. The verification shall be considered successful when measurements show that the peak overall sound pressure levels are less than 82dB peak for impulse noise (not weighted) and 68 dBA (A-weighted) for intermittent noise.

Verification Success Criteria: Intermediate testing and analysis should be performed and reviewed by NASA to ensure confidence that compliance with this requirement will be met and to preclude late impacts to cost, schedule, and hardware.

DVO-HLS-HMTA-0079 Impulse Noise Limit

Statement: Test - The impulse noise limit shall be verified by test. The SPL measurements for this verification shall be made using the actual flight equipment (each serialized unit). Formal verification is not required for equipment with impulse noises that have peak overall SPLs of less than 110 dB. Peak-hold sound pressure level measurements shall be made using a Type 1 sound level meter on all equipment that emits significant impulse noise at expected head locations. The frequency response of the sound level meter shall extend to at least 6 Hz at its lower limit. Measurement locations relative to specific noise sources must correspond to the shortest distance from the loudest point on the hardware to the closest possible

crewmember head location. This verification shall be considered successful when the test results show that the peak overall sound pressure level measurements are less than 140 dB.

Verification Success Criteria: Serialized units must be verified individually because different units produced from the same design can generate significantly different noise levels. Significant impulse noise sources consist of valves, burst disks, and any other impulse noise source potentially greater than 110 dB SPL. Noise attenuation gained by the use of hearing protection is not to be considered toward the compliance of this requirement, because hearing protection may not always be worn. Intermediate testing and analysis should be performed and reviewed by NASA to ensure confidence that compliance with this requirement will be met and to preclude late impacts to cost, schedule, and hardware.

DVO-HLS-HMTA-0080 Narrow-Band Noise Limits

Statement: Test - The tonal and narrow-band noise limit shall be verified by test. The measurements shall be made within the vehicle in the flight configuration with integrated GFE, stowage, vehicle installations, and closeouts installed. Hardware shall be operated across the expected range of operational settings (including settings corresponding to the expected highest noise levels). Equivalent-continuous sound level, Leq, measurements shall be made within each octave band using a Type 1 integrating-averaging sound level meter with a 20-second averaging time. Tonal and narrow-band component measurements shall also be made using a Fast Fourier Transform (FFT) with a frequency resolution of 1 Hz. Measurements shall be made at expected work and head locations during sleep.

Verification Success Criteria: The verification shall be considered successful when the test indicates that the maximum levels of tones and narrow band components, measured at all work and head locations during sleep, is at least 10 dB less than the values in the HLS-HMTA-0076, Table 20 Octave Band SPL Noise of the octave band that contains the component or tone.

DVO-HLS-HMTA-0081 Infrasonic Sound Pressure Limits

Statement: Analysis and Test - The Ascent and Landing Phases - Infrasonic Noise Limit shall be verified by test and analysis. The maximum noise level measured at the crewmember’s ears shall be determined by flight-testing. The test and analysis shall consist of estimating the maximum sound level at the crewmember’s ear by combining significant noise sources from estimates of rocket noise and external flow boundary layer noise, and including acoustic insertion losses of acoustic isolation and protective devices. The rocket noise should be determined by test. Acoustic insertion losses of the pressure shell and other materials shall be determined by test. The effectiveness of hearing protection, headsets, and helmets is not allowed for this verification. Sound pressure measurements shall be made over a frequency range from 1 to 20 Hz, using a Type 1 integrating-averaging sound level meter at expected work station head

locations. The infrasonic noise level shall be measured via a 20 second Leq (slow time weighting).

Verification Success Criteria: Rocket and aerodynamic sources present during ascent, landing, abort, or other long duration rocket firings are considered to be the only credible noise sources for this requirement. The verification shall be considered successful when the test and analysis indicate that the unweighted overall sound pressure level is 150 dB or less, at each expected work station head-location.

DVO-HLS-HMTA-0082 Noise Limit for Personal Communication Devices
Statement: Test - The personal communication device SPL limit shall be verified by test. Measurements shall be made using a Type 1 integrating-averaging sound level meter with an artificial ear or head simulator.

Verification Success Criteria: The verification shall be considered successful when the test shows that the measured maximum SPL at the crewmember's ear is 115 dBA or less at maximum specified device audio input level and the maximum audio output volume setting.

DVO-HLS-HMTA-0083 Vibration Limits
Statement: Inspection - Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 6090, 6091, 6092, 6093 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0084 Vibration Exposures During Dynamic Phases of Flight
Statement: Analysis and Test - The dynamic phases of flight vibration exposure health limit shall be verified by analysis supported by test. The analysis shall consist of a simulation of the vibration levels at the crew seat and/or other body supporting surfaces, assuming that the seat and/or other supporting surfaces are relatively rigid structures. The weighted acceleration shall be calculated in accordance with ISO 2631-1:1997, using the frequency weighting Wd for the body X and Y directions, Wk for the Z direction, and a multiplying factor k=1.4 in the X and Y directions and k=1 in the Z direction (ISO 2631-1:1997, Tables 1 and 3 and Figure 1, and Section 7.2). Test data obtained from ground vibration testing and/or flight tests shall be used to support validation of the model and to evaluate vehicle vibration under all dynamic phases of flight. Testing and analysis will require measurement and simulation of translational acceleration along the three orthogonal axes, X, Y, and Z of the seat and/or other body supporting surfaces, at an acceptable sampling rate to determine the vibration profile.

Objective: The vibration levels that reach the crew are the result of several factors provided by the launch vehicle, the crew vehicle, connecting structure, means of vibration attenuation, etc. For cases where the crew is suited, the suit needs to be considered as an integral part of the connecting structure. The resultant vibration levels will likely be too complex to be determined from analysis alone. In order to determine if the vehicle has met the tolerance vibration limit, which is a matter of crew safety, actual vehicle test data are required to understand what the crew will experience and to provide data for additional analyses. The measurement of acceleration is to be made at the crew seat and/or other body supporting surfaces and assumes these surfaces are relatively rigid. ISO 2631-1:1997 calls for the measurement of acceleration at the supporting surfaces between a seat and the occupant to account for the effects of any resilient cushion material. The measurement is being made on the rigid seat (couch) structure with respect to the body's X, Y, and Z coordinates defined in ISO 2631-1:1997 Figure 1 and in HSIR Appendix C. It is assumed that the occupant will be rigidly coupled to the supporting surfaces by the restraint system, minimizing any amplification of vibration.

Verification Success Criteria: The verification shall be successful when the analyses indicate with acceptable confidence and acceptable consumer risk that the vectorial sum of the X, Y, and Z frequency-weighted accelerations between 0.5 and 80 Hz of the rigid crew seat does not exceed the levels and exposure durations in HS3105, Table 21 Frequency-Weighted Vibration Limits by Exposure Time During Dynamic Phases.

DVO-HLS-HMTA-0085 Long-Duration Vibration Exposure Limits for Health during Non-Sleep Phases of Mission

Statement: Test - Long-Duration Vibration Exposure Limits for Health during Non-Sleep Phases of Mission shall be verified by analysis supported by test. The analysis shall consist of a simulation of the vibration levels at the crew seat and/or other body supporting surfaces, assuming that the seat and/or other supporting surfaces are relatively rigid structures. The weighted acceleration shall be calculated in accordance with ISO 2631-1:1997, using the frequency weighting Wd for the body X and Y directions, Wk for the Z direction, and a multiplying factor k=1.4 in the X and Y directions and k=1 in the Z direction (ISO 2631-1:1997, Tables 1 and 3 and Figure 1, and Section 7.2). Test data obtained from ground vibration testing and/or flight tests shall be used to support validation of the model and to evaluate vehicle vibration under all dynamic phases of flight. Testing and analysis will require measurement and simulation of translational acceleration along the three orthogonal axes, X, Y, and Z of the seat and/or other body supporting surfaces, at an acceptable sampling rate to determine the vibration profile.

Objective: The vibration levels that reach the crew are the result of several factors provided by the launch vehicle, the crew vehicle, connecting structure, means of vibration attenuation, etc. For cases where the crew is suited, the suit needs to be considered as an integral part of the connecting structure. The resultant vibration

levels will likely be too complex to be determined from analysis alone. In order to determine if the vehicle has met the tolerance vibration limit, actual vehicle test data are required to understand what the crew will experience and to provide data for additional analyses. The measurement of acceleration is to be made at the crew seat and/or other body supporting surfaces and assumes these surfaces are relatively rigid. ISO 2631-1:1997 calls for the measurement of acceleration at the supporting surfaces between a seat and the occupant to account for the effects of any resilient cushion material. The measurement is being made on the rigid seat (couch) structure with respect to the body's X, Y, and Z coordinates defined in ISO 2631-1:1997 Figure 1 and in HSIR Appendix C. It is assumed that the occupant will be rigidly coupled to the supporting surfaces by the restraint system, minimizing any amplification of vibration.

Verification Success Criteria: The verification shall be successful when the analyses indicate with acceptable confidence and acceptable consumer risk that the vectorial sum of the X, Y, and Z frequency-weighted accelerations between 0.5 and 80 Hz of the rigid crew seat does not exceed the minimum health guidance caution zone level defined by Figure B.1 in ISO 2631-1:1997(E), Annex B.

DVO-HLS-HMTA-0086 Vibration Exposure Limits during Sleep

Statement: Analysis and Test - The crew sleep vibration limit requirement shall be verified by analysis supported by test. The analysis shall use test data collected from flight tests to obtain flight vibration profiles of the vehicle's crew compartment after orbital insertion. Testing will require continuous on-board measurement of translational acceleration in the three orthogonal axes X, Y, and Z on the support surfaces of the crew compartment used for rest areas. The measurement should reflect the acceleration levels expected to occur during an 8-hour sleep period. The recorded test profile shall then drive an analytic simulation of crew compartment vibration. In accordance with International Standards Organization (ISO) Standard 20283-5:2016(E), the minimum measurement period shall be 2 minutes in case of significant vibration frequency content below 2 Hz. All acceleration measurements shall be weighted in accordance with ISO 20283-5:2016(E), Annex A using the frequency weighting Wa (Table A.1).

Verification Success Criteria: The verification shall be considered successful when the analysis indicates with acceptable confidence (e.g., [Gaussian-distributed Monte Carlo studies with dispersed GN&C, and vehicle and environmental factors) and acceptable consumer risk that the simulated vibration levels on the support surfaces of the rest areas are less than 0.01 g frequency-weighted rms acceleration in each of the X, Y, and Z axes between 1.0 and 80 Hz for each 2-minute interval during an 8-hour crew sleep period. Because the final configuration of the vehicle and equipment will not be known until close to flight, an effective means of ensuring that sustained vibration levels are met is to perform an analysis of compartment vibration using available flight test data set and the occupant to account for the effects of any resilient cushion material. The guidelines given for health in ISO 2631-1:1997 are based primarily on

the upright seated occupant, not the semi-supine occupant. The measurement is being made on the rigid seat (couch) structure with respect to the body's X, Y, and Z coordinates defined in ISO 2631-1:1997 Figure 1 and in HSIR Appendix C. It is assumed that the occupant will be rigidly coupled to the couch by the restraint system, minimizing any amplification of vibration by the cushion material. The tolerance data collected in the 1960s reported the accelerations of the vibration platform to which the couch was rigidly attached.

DVO-HLS-HMTA-0087 Vibration Limits for Performance

Statement: Analysis and Test - The flight vibration exposure limit for visual performance during launch shall be verified by analysis supported by test. The analysis shall use a provided integrated vehicle reference model, including an appropriate model of the seat occupant for loading of the seat, which allows modification for evaluation of the design against the requirement. Test data obtained from ground vibration testing and/or flight tests shall be used to support validation of the model. The analysis shall use the population of forcing functions as an aid to the determination the structural response and the uncertainty of the response. The result will be a population of responses at the operator seats. There are no frequency- or direction-dependent weighting factors that enter into these calculations. The verification shall be considered successful when the analysis shows there is a 99.87% probability (i.e., 3-sigma bounding for Gaussian-distributed Monte Carlo studies) with 50% consumer risk that the dynamic load requirement at the operator seat in the reference model does not exceed the levels and exposure durations in HS3135, table Crew Limits for Vibration in the 10-13 Hz Frequency Band

Verification Success Criteria: The verification provides a methodology that allows Orion to evaluate the design and its contribution to the integrated vehicle response to the thrust oscillation frequency at the crew seat.

DVO-HLS-HMTA-0088 Radiation protection, limitations and monitoring

Statement: Inspection - Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 6097, 6100 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0089 Crew Radiation Exposure Limits

Statement: Analysis - Implementation of the ALARA principle shall be verified by analysis.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that the As Low as Reasonably Achievable principle is applied.

DVO-HLS-HMTA-0090 Ionizing Radiation Alerting

Statement: Demonstration - The absorbed dose alerting shall be verified by demonstration. The demonstration shall consist of setting thresholds at 0.01 mGy/min, 0.05 mGy/min, 1 mGy/min, and 10 mGy/min. The demonstration shall use a simulated data stream identical format to the absorbed dose data stream, input into the vehicle data management system, or equivalent, that will exceed each of the above thresholds for three consecutive readings. The verification shall be considered successful when the demonstration shows that an alert in the vehicle data management system is generated when each of these thresholds is exceeded for three consecutive readings.

Verification Success Criteria: Demonstration is the necessary method for verification of this requirement. Due to the high dose rates required to exceed the alarm thresholds, it is not practical to use a flight equivalent instrument as the data source. The data stream will be simulated with data identical to the absorbed dose data format. Confirmation of the various alarm threshold settings and ability to generate an alarm if they are exceeded is important to ensure reliability of the alarm function and protect crewmembers during high dose rate conditions. The alarm testing does not require analysis but will verify an alarm or no alarm condition.

DVO-HLS-HMTA-0091 Natural Sunlight Exposure Limits

Statement: Analysis and Test - Crewmember exposure limits shall be verified by test and analysis. The test shall measure the transmittance of all transparent and translucent apertures and radiance of artificial sources from 180 nm–1,400 nm in 1-nm increments. Transmittance measurements may be taken using witness samples in the normal flight configuration if the witness samples are large enough to capture the enhanced transmittance realized from multi-pane reflections; otherwise, transmittance measurements shall be performed on flight articles. Spectral radiance measurements of artificial sources shall be done by type and lot. The test report shall be provided to NASA, including the transmittance and radiance data in easier to use data formats (i.e., CSV files, DAT file, Excel, etc.). The analysis shall be performed using he transmittance and radiance values obtained during the test.

The verification shall be considered successful when the analysis shows that the exposure limits are satisfied per Table 30, Exposure Limits for Different Damage Mechanisms.

Table 30: 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)	$T_{max} \geq 0.25s$ (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 shall 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 shall not be utilized due to substantial differences in hazard functions. These limits do not account for forced chronic solar viewing.

DVO-HLS-HMTA-0092 Artificial Light Limits for Visible sources below 10,000 nits

Statement: Analysis or Test - Crewmember exposure limits shall be verified by test or analysis. The test shall measure the transmittance of all transparent and translucent apertures and radiance of artificial sources from 180 nm – 1,400 nm in 1-nm increments. Transmittance measurements may be taken using witness samples in the normal flight configuration if the witness samples are large enough to capture the enhanced transmittance realized from multi-pane reflections; otherwise, transmittance measurements shall be performed on flight articles. Spectral radiance measurements of artificial sources shall be done by type and lot. The test report shall be provided to NASA, including the transmittance and radiance data, along with a graphical representation of these data. The analysis shall be performed using he transmittance and radiance values obtained during the test.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that the exposure limits are satisfied per Table 30, Exposure Limits for Different Damage Mechanisms.

DVO-HLS-HMTA-0093 Artificial Light Exposure Limits for Visible sources above 10,000 nits and Infrared (IR) Sources

Statement: Analysis or Test - Artificial Light Exposure Limits shall be verified by test or analysis. The analysis shall assess the visible artificial light sources and provide vendor data or test data showing ≤10,000 nits measured at <1cm from the source.

Verification Success Criteria: Verification is considered successful when (A) Calculations per ACGIH (2014 or later) show crew exposure does not exceed the TLV, or (B) Test and inspection of as-built hardware confirms the visible or IR source is controlled or contained.

DVO-HLS-HMTA-0094 Artificial Light Exposure Limits for Ultraviolet (UV) Sources
Statement: Inspection - This requirement shall be verified by inspection of the UV source containment. Acceptable methods of containment included the use of light-tight structures and enclosures to fully contain the UV at the source, or UV optical light obstruction by other means (e.g. screens, shields, filters) before reaching the crew to prevent exposure.

Verification Success Criteria: Verification is considered successful when (A) Review of end item design confirms containment, and (B) Inspection of as-built hardware confirms containment.

DVO-HLS-HMTA-0095 RF Non-Ionizing Radiation Exposure Limits
Statement: Analysis - Crew exposure to radio-frequency electromagnetic fields shall be verified by analysis. Data shall be analyzed and verified both for individual and combined RF EM fields. A model of additive and synergistic RF EM fields shall be generated to show projected crew exposures in crew accessible areas, both internal and external to the vehicle.

Verification Success Criteria: The verification shall be considered successful when the analysis shows crew exposures are within the limits specified in Table 31 and Figure 9. Note: The Crew RF Hazard Analysis Tool developed by the Space Radiation Analysis Group may be used to aid with RF hazard analyses for crew exposure and is available through NAMS request.

Table 31: Maximum Permissible Exposure (MPE) Limits for Radio-Frequency Electromagnetic Fields (modified from IEEE C95.1-2005 standard, 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 (minutes)	
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 – 5,000	–	–	$f/150$	30	
5,000 – 15,000	–	–	$f/150$	$150/f_G$	
15,000 – 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 arecompared 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 (for further details please see IEEE C95.1-2005, notes to Table 8 and Table 9), are compared with the MPEs in the Table.

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.

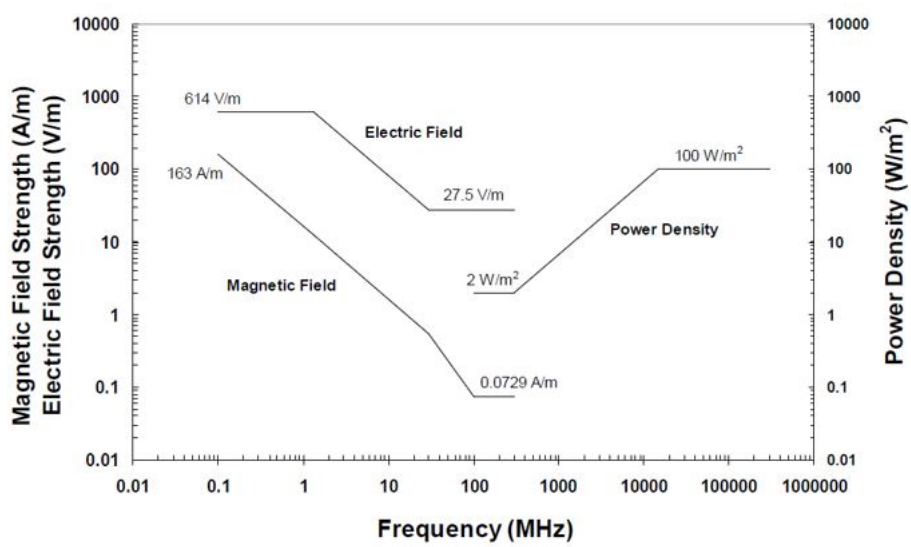


Figure 9: Occupational Exposure Limits for Radio-Frequency Electromagnetic Fields illustrated to show body resonance effects around 100 MHz (modified from IEEE C95.1-2005 standard, lower tier)

DVO-HLS-HMTA-0096 Laser Exposure Limits
Statement: Analysis - Ocular and dermal exposure from laser systems shall be verified by analysis. The analysis shall be performed as defined by American National Standards Institute (ANSI) standard, ANSI Z136.1, 2014 “American National Standard for Safe Use of Lasers”. To prove that the ANSI standard is met, the laser system must be analyzed with regard to its operating parameters, operational configuration, and isolation and containment measures.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that ocular exposure is within the limits in ANSI Z136.1, 2014 Table 5 (ocular) and Table 7 (dermal).

DVO-HLS-HMTA-0097 Solar Particle Event (SPE) protection
Statement: Analysis - Radiation exposure shall be verified by analysis. The verification shall be considered successful when the analysis shows that the gray equivalent to BFO incurred by any crewmember within the vehicle does not exceed 250 mGy-Eq.

Objective: Analysis must be used to verify this requirement. The complexity of radiation environment, radiation transport calculations, and vehicle/shielding geometry make verification by other methods intractable. Selection of calculation inputs and algorithms follow a conservative approach and the calculation methods are state of the art for space radiation analysis.

DVO-HLS-HMTA-0098 Nutrition Stowage Care
Statement: Inspection - Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 7008, 7009, 7010 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0099 Food Preparation
Statement: Demonstration - Demonstrate that all foods and food related items can be stowed in the allotted volume, and that equipment heats food to required temperatures.

DVO-HLS-HMTA-0100 Food Preparation and Cleanup
Statement: Demonstration - Demonstrate that food for all crewmembers can be prepared (e.g. rehydrated, heated) for crew to eat together within the allotted time.

DVO-HLS-HMTA-0101 Food Contamination Control
Statement: Analysis - Assess that design of locations prevent cross-contamination.

DVO-HLS-HMTA-0102 Food and Beverage Heating
Statement: Inspection - Food and Beverage Heating shall be verified by inspection of drawings.

DVO-HLS-HMTA-0105 Personal Hygiene Capability
Statement: Analysis and Demonstration - The capability for oral hygiene, personal grooming, and body cleansing shall be verified by demonstration and analysis. The demonstration shall be considered successful when these activities can be successfully performed in the vehicle in a 1G environment. The analysis shall be considered successful when a task analysis shows that these activities can be successfully performed in the gravitational environments applicable to the vehicle.

Objective: Verification by demonstration will be performed in 1G environment; task analyses for microgravity and lunar gravity must show that tasks can be successfully performed in relevant gravitational environments.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0106 Crew Task Volume
Statement: Inspection - Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 7018 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0107 Dining Accommodations
Statement: Analysis - The verification of Dining Accommodations shall be verified by analysis

DVO-HLS-HMTA-0109 Personal Hygiene Provision
Statement: Inspection - The provision of stowage for personal hygiene items shall be verified by inspection. The inspection shall be of the engineering drawings.

Verification Success Criteria: The inspection shall be considered successful when stowage locations for personal hygiene items for each crewmember are present in the engineering drawings.

DVO-HLS-HMTA-0111 Body Waste Management Capability

Statement: Analysis and Demonstration - Body waste management capability shall be verified by analysis and demonstration. The analysis shall be based upon operations analysis of historical waste generation.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows that the system can safely collect and contain the body waste predicted by the analysis for the DRM.

DVO-HLS-HMTA-0112 Body Waste Management System Location
Statement: Inspection - Body waste system location shall be verified by inspection. CAD drawings of the design layout shall be inspected to confirm that the body waste management system is isolated from food prep and dining areas.

Verification Success Criteria: The verification shall be considered successful when inspection shows that the body waste location is isolated from food and dining areas to prevent contamination and support psychological health.

DVO-HLS-HMTA-0122 Medical Sharps Disposal
Statement: Demonstration - Medical sharps containment shall be verified by demonstration. The demonstration shall consist of disposing items, including medical sharps, into the trash management system and showing that containment is safe, complete, and independent of gravity.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows that the trash management system contains these waste items.

DVO-HLS-HMTA-0123 Deceased Crew
Statement: Analysis and Inspection - The ability to handle deceased crewmembers shall be verified by analysis and inspection. The analysis shall state the plan for containing and preserving the deceased and the method of final disposition of remains. The inspection shall consist of a review to ensure that appropriate hardware is available and procedures are developed to contain and preserve remains until completion of final disposition of the remains.

Verification Success Criteria: The verification shall be considered successful when the plan is developed, hardware is identified and available to contain, preserve and complete disposition of the remains.

DVO-HLS-HMTA-0124 Stowage Provisions
Statement: Inspection, Analysis, and Test - Provisions for stowage shall be verified by inspection and analysis or test. Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 7050, 7054, 7056, 7057 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances. Lists of stowed items and drawings shall be inspected to confirm that sufficient volume and restraint mechanisms are provided for

all items that are planned to be stowed. Adequacy of restraints to protect stowed items under expected gravity, acceleration, and vibration environments shall be evaluated by analysis or test.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA. The verification shall be considered successful when inspection and analysis or test confirm that defined stowage areas and adequate restraints are provided for all planned stowage items.

DVO-HLS-HMTA-0128 Stowage Restraints
Statement: Analysis - The restraint of stowed items during periods of expected acceleration and vibration shall be verified by analysis. The analysis shall evaluate the effect of expected acceleration and vibration on the restraints of stowed items.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that the restraint system is sufficient for the volume and mass of stowed items.

DVO-HLS-HMTA-0130 Stowage Operation without Tools
Statement: Demonstration - The tool-free operation of stowage systems shall be verified by demonstration. The demonstration shall be performed using high-fidelity stowage components. The demonstration shall consist of a subject accessing and operating stowage compartments.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows that all stowage compartments are accessible and operable without the use of any tools.

DVO-HLS-HMTA-0131 Stowage Access while Suited
Statement: Analysis and Test - Stowage Access while Suited shall be verified by test and analysis. If able to perform suited-pressurized testing: evaluation of task/worksite analysis. If unable to perform suited-pressurized testing: must be demonstrated by NASA.
The test shall occur in a qualification vehicle or a high-fidelity mockup, and the vehicle or mockup shall be in the flight configuration with integrated GFE, stowage, vehicle installations, and closeouts installed. The test shall be performed in a high fidelity pressurized suit. A task analysis and worksite analysis under the time constraints of contingency operations shall be conducted.

DVO-HLS-HMTA-0138 Trash Accommodation
Statement: Inspection - Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 7064, 7065, 7066, 7067, 7068, 7013 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0139 Trash Volume Allocation
Statement: Analysis and Inspection - Trash Volume Allocation shall be verified by analysis and inspection.

DVO-HLS-HMTA-0140 Trash Stowage Interference
Statement: Analysis and Inspection - Trash Stowage Interface shall be verified by analysis and inspection.

DVO-HLS-HMTA-0141 Trash Odor Control
Statement: Analysis and Demonstration - The odor control for trash management equipment shall be verified by analysis and demonstration with subjective evaluation. Analysis shall identify and characterize trash types and odors and detail the trash containment designs. Demonstration shall be performed using flight-representative trash containers and representative odor sources. The demonstration shall be performed under representative environmental conditions (e.g., vehicle habitable volume, temperature, humidity, airflow, etc.), while exercising expected trash operations for the duration expected until trash disposal. NASA crew and/or SMEs will provide subjective evaluation (e.g., discomfort scale) as the measure of whether odors are contained during the demonstration.

Verification Success Criteria: The verification shall be considered successful when analysis and demonstration evaluation show that the trash management system controls odors from permeating the habitable volume of the vehicle.

DVO-HLS-HMTA-0142 Trash Contamination Control
Statement: Analysis - The prevention of trash release shall be verified by analysis. The analysis shall include a review of the trash management system design. The analysis shall examine date samples gathered from the surrounding environment after repeated operations of the trash management system where microorganisms are present.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that microorganisms in trash are not released outside of the trash management system.

DVO-HLS-HMTA-0143 Food System Waste
Statement: Analysis - Food System Waste shall be verified by task analysis.

DVO-HLS-HMTA-0144 Sleep

Statement: Inspection - Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 7073 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0146 Partial-g Sleeping
Statement: Demonstration - Partial-g Sleeping shall be verified by demonstration. The demonstration shall occur in a qualification vehicle, a high-fidelity mockup, or high fidelity part-task mockup and the vehicle or mockup shall be in the flight configuration.

DVO-HLS-HMTA-0147 Clothing
Statement: Inspection - Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 7074, 7075, 7076, 7077 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0148 Architecture
Statement: Inspection - Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 8001, 8002, 8003, 8007, 8008, 8009, 8014, 8015, 8018, 8019, 8021, 11002, 11005 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0149 Volume Allocation
Statement: Inspection and Demonstration - Functional volume design shall be verified through inspection and demonstration. NASA shall inspect analysis performed to confirm that expected mission and safety critical tasks are defined and used to drive functional arrangement of locations and allocation of volumes to support crew operations. NASA shall inspect CAD 3D models of the vehicle layout showing areas designed for mission and safety critical crew activities, especially those that are concurrent or adjacent. A demonstration of critical expected mission tasks involving both unsuited and suited tasks (with the full crew wearing LEA suits) shall be performed. The demonstration shall be performed in a flight-representative vehicle configuration. The verification shall be considered successful when inspection and

demonstration show that defined functional volumes are sufficient to support successful completion of expected critical mission tasks.

Verification Success Criteria: No further rationale is required

DVO-HLS-HMTA-0150 Volume for Crewmember Accommodation
Statement: Demonstration and Test - Volume for Crewmember Accommodation shall be verified by demonstration or test. The demonstration/test shall occur in a physical mockup with well-defined translation paths, equipment placement, and work volumes (Fidelity of the mockup does not need to be high throughout, just in areas where translation and work would occur.). The demonstration/test shall be performed with the expected number of crew members.

DVO-HLS-HMTA-0151 Volume for Mission Accommodation
Statement: Analysis - Volume for mission and crew accommodation shall be verified by inspection, analysis and demonstration. Iterative process of design, analysis and test should follow the process outlined by JSC/SA/Chief Medical Officer in Memo SA-16-156. A task analysis shall be performed to identify crew tasks required for nominal and off-nominal operation for the applicable mission duration, phases and environments. An analysis shall be performed to show functional arrangement and allocation of volumes to support crew operations are consistent with the anthropometric and range of motion data. The inspection shall include the review of CAD 3D models showing vehicle layout accommodation of expected crew tasks, anthropometry and range of motion. A demonstration shall be performed of critical expected mission tasks in a flight representative vehicle in the flight configuration. The verification shall be considered successful when the analysis, inspection, and demonstration show that the volume accommodates the required measurements and that the crew, in all required clothing, can complete the tasks identified.

DVO-HLS-HMTA-0154 Spatial Orientation
Statement: Inspection - Spatial Orientation shall be verified by inspection of design (a high-fidelity CAD or VR model that includes flight-like interfaces, labels, tags, and other visual cues) for orientation of work stations, as well as inspection of task analysis/worksite analysis to ensure tasks to be completed within the volume adhere to the established directional orientation.

DVO-HLS-HMTA-0155 Consistent Orientation
Statement: Inspection - Consistent Orientation shall be verified by inspection of design (a high-fidelity CAD or VR model that includes flight-like interfaces, equipment, and labels).

DVO-HLS-HMTA-0156 Interface Orientation
Statement: Inspection - Interface Orientation shall be verified by inspection of design (a high-fidelity CAD or VR model that includes flight-like interfaces, equipment, and labels).

DVO-HLS-HMTA-0161 Emergency Translation Paths

Statement: Analysis and Demonstration - Translation paths shall be verified by analysis and demonstration. Analysis shall include identifying suited operation scenarios for crew ingress and egress (nominal and off-nominal) from one vehicle or transfer between two, including the likely pressurization state of suits. Analysis shall consist of using high-fidelity computer graphic models. The models shall include the vehicles, suited crewmembers, and suited crewmembers' movement through the translation paths. The demonstration shall occur in a high-fidelity mockup in 1 g in the flight configuration with integrated GFE, stowage, vehicle installations, and closeouts installed. The demonstration shall consist of suited subjects performing ingress and egress (nominal and off-nominal) operation scenarios.

Verification Success Criteria: The verification shall be considered successful when the analysis and demonstration show that suited ingress and, egress (nominal and off-nominal) operations can be performed without being hampered by protrusions and snag points.

DVO-HLS-HMTA-0162 Ingress, Egress and Escape Translation Paths

Statement: Analysis and Demonstration - Translation paths shall be verified by analysis and demonstration. Analysis shall include identifying suited operation scenarios for crew ingress and egress (nominal and off-nominal) from one vehicle or transfer between two, including the likely pressurization state of suits. Analysis shall consist of using high-fidelity computer graphic models. The models shall include the vehicles, suited crewmembers, and suited crewmembers' movement through the translation paths. The demonstration shall occur in a high-fidelity mockup in 1 g in the flight configuration with integrated GFE, stowage, vehicle installations, and closeouts installed. The demonstration shall consist of suited subjects performing ingress and egress (nominal and off-nominal) operation scenarios.

Verification Success Criteria: The verification shall be considered successful when the analysis and demonstration show that suited ingress and, egress (nominal and off-nominal) operations can be performed without being hampered by protrusions and snag points.

DVO-HLS-HMTA-0165 Hazard Avoidance

Statement: Analysis and Demonstration - Translation paths shall be verified by analysis and demonstration. Analysis shall include identifying suited operation scenarios for crew ingress and egress (nominal and off-nominal) from one vehicle or transfer between two, including the likely pressurization state of suits. Analysis shall consist of using high-fidelity computer graphic models. The models shall include the vehicles, suited crewmembers, and suited crewmembers' movement through the translation paths. The demonstration shall occur in a high-fidelity mockup in 1 g in the flight configuration with integrated GFE, stowage, vehicle installations, and closeouts

installed. The demonstration shall consist of suited subjects performing ingress and egress (nominal and off-nominal) operation scenarios.

Verification Success Criteria: The verification shall be considered successful when the analysis and demonstration show that suited ingress and, egress (nominal and off-nominal) operations can be performed without being hampered by protrusions and snag points.

DVO-HLS-HMTA-0166 Path Visibility
Statement: Inspection and Test - The visibility of emergency egress paths shall be verified by inspection and test. Drawings for emergency egress pathways shall be inspected to confirm that lighting or visible markers are implemented so that the crews' emergency egress pathway is clearly marked. If powered emergency lighting is used, test shall be performed to confirm that emergency lighting will automatically illuminate when needed so that the crews' emergency egress pathway is clearly marked. If photoluminescent decals are used, test shall be performed to confirm the decals can be adequately charged by light sources in their installed configuration to provide visible indication of the crews' emergency egress pathway. The verification shall be successful when inspection and test show that emergency egress pathways are clearly marked and visible to crew.

DVO-HLS-HMTA-0167 Crew Ingress/Egress Translation Path in Space
Statement: Analysis and Demonstration - The translation path for the assisted in-space ingress and egress of an incapacitated pressurized-suited crewmember shall be verified by analysis and demonstration. The analysis shall consist of volumetric modeling of the in-space translation path and human models of the incapacitated crewmember and the assisting crewmembers. The demonstration shall consist of a high-fidelity mockup or flight vehicle and use of a simulated pressurized-suited crewmember with weight representative of the applicable gravity environment and the assisting crewmembers. The verification shall be considered successful when the analysis and demonstration prove that the in-space translation path provides sufficient clearance for the assisted ingress and egress of an incapacitated crewmember.

Verification Success Criteria: No further rationale is required

DVO-HLS-HMTA-0168 Translation Paths for Suited Crewmembers
Statement: Analysis and Demonstration - Translation paths shall be verified by analysis and demonstration. Analysis shall consist of performing unsuited operation scenarios using high- fidelity computer graphic models. The models shall include the vehicle, unsuited crewmembers, and unsuited crewmembers' movement through the translation paths. The demonstration shall occur in a high-fidelity mockup in 1 g in the flight configuration with integrated GFE, stowage, vehicle installations, and closeouts installed. The demonstration shall consist of unsuited subjects performing operation scenarios.

Verification Success Criteria: The verification shall be considered successful when the analysis and demonstration show that unsuited operations can be performed.

DVO-HLS-HMTA-0169 EVA Translation Path Hazard Avoidance
Statement: Analysis - EVA Translation Path Hazard Avoidance shall be verified by analysis. The analysis shall consist of a task analysis to define appropriate EVA paths.

DVO-HLS-HMTA-0170 Hatches - Initial
Statement: Analysis and Demonstration - Hatch operability by a suited crewmember shall be verified by analysis and demonstration. Analysis shall include identifying suited operation scenarios for crew ingress and egress (nominal and off-nominal) from one vehicle or transfer between two, including the likely pressurization state of suits. The demonstration shall occur in a qualification vehicle or a high-fidelity mockup, and the vehicle or mockup shall be in the flight configuration with integrated GFE, stowage, vehicle installations, and closeouts installed. The demonstration shall consist of one suited subject performing the following four tasks: unlatching and fully opening each hatch from the inside, unlatching and fully opening each hatch from the outside, closing and latching each fully-opened hatch from the inside, and closing and latching each fully-opened hatch from the outside. The verification shall be considered successful when the analysis and demonstration show that a suited crewmember has successfully completed all tasks. Further, Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 8001, 8002, 8003, 8007, 8008, 8009, 8014, 8015, 8018, 8019, 8021, 11002, 11005 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0171 Hatch Cover and Door Operation without Tools
Statement: Demonstration - Hatch operability without the use of tools shall be verified by demonstration. The demonstration shall occur in a qualification vehicle or a high-fidelity mockup, and the vehicle or mockup shall be in the flight configuration with integrated GFE, stowage, vehicle installations, and closeouts installed. The demonstration shall consist of one suited subject performing the following four tasks: unlatching and fully opening each hatch from the inside, unlatching and fully opening each hatch from the outside, closing and latching each fully-opened hatch from the inside, and closing and latching each fully-opened hatch from the outside. The demonstration task completion time shall be measured in seconds.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows that the hatch is operable without the use of tools.

DVO-HLS-HMTA-0172 Unlatching Hatch Covers
Statement: Demonstration - Hatch unlatching shall be verified by demonstration. The demonstration shall occur in a qualification vehicle or a high-fidelity mockup, and the vehicle or mockup shall be in the flight configuration with integrated GFE, stowage, vehicle installations, and closeouts installed. The demonstration shall consist of one suited subject opening the hatch from a closed and latched position.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows that unlatching requires two distinct and sequential operations.

DVO-HLS-HMTA-0173 Hatch Cover and Door Operating Times
Statement: Demonstration - Hatch operability in 60 seconds shall be verified by demonstration. The demonstration shall occur in a qualification vehicle or a high-fidelity mockup, and the vehicle or mockup shall be in the flight configuration with integrated GFE, stowage, vehicle installations, and closeouts installed. The demonstration shall demonstrate 0-g operability by performing the tasks in 1 g and applying a 0-g factor to the task completion time. The demonstration shall consist of one suited subject performing the following four tasks: unlatching and fully opening each hatch from the inside, unlatching and fully opening each hatch from the outside, closing and latching each fully-opened hatch from the inside, and closing and latching each fully-opened hatch from the outside. The demonstration task completion time shall be measured in seconds.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows that the completion time is 60 seconds or less per task.

DVO-HLS-HMTA-0174 Hatch Cover and Door Operating Force
Statement: Analysis and Test - The hatch operating forces shall be verified by test and analysis. The force required to perform full hatch opening shall be measured using a force strain gauge through all steps of opening the hatch including hatch retention mechanisms, crank operation to fully unlatch, and opening/removing the cover. Analysis shall be performed to account for pressure differential, gravity, or orientation impacts on hatch operation.

DVO-HLS-HMTA-0175 Hatch Cover and Door Gravity Operations
Statement: Analysis - Hatch Cover and Door Gravity Operations shall be verified by analysis. This verification shall consist of an inspection of task analysis and worksite analysis.

DVO-HLS-HMTA-0176 Hatch Size and Shape
Statement: Analysis and Demonstration - Translation paths shall be verified by analysis and demonstration. Analysis shall include identifying suited operation scenarios for crew ingress and egress (nominal and off-nominal) from one vehicle or transfer between two, including the likely pressurization state of suits. Analysis shall consist of using high-fidelity computer graphic models. The models shall include the

vehicles, suited crewmembers, and suited crewmembers' movement through the translation paths. The demonstration shall occur in a high-fidelity mockup in 1 g in the flight configuration with integrated GFE, stowage, vehicle installations, and closeouts installed. The demonstration shall consist of suited subjects performing ingress and egress (nominal and off-nominal) operation scenarios.

Verification Success Criteria: The verification shall be considered successful when the analysis and demonstration show that suited ingress and, egress (nominal and off-nominal) operations can be performed without being hampered by protrusions and snag points.

DVO-HLS-HMTA-0177 Pressure Equalization across the Hatch
Statement: Analysis and Demonstration - Manual pressure equalization on each side of the hatch shall be verified by analysis and demonstration. Analysis shall include identifying suited operation scenarios including the likely pressurization state of suits. The demonstration shall occur in the vehicle or a high-fidelity mockup. The demonstration shall consist of performing a manual pressure equalization procedure on both sides of each hatch under the range of expected internal/external pressure levels.

Verification Success Criteria: The verification shall be considered successful when the analysis and demonstration show that a suited crewmember can complete the procedure.

DVO-HLS-HMTA-0178 Visibility across the Hatch
Statement: Inspection and Demonstration - The verification of Visibility across Hatches shall be verified by inspection of drawings and demonstration.

DVO-HLS-HMTA-0179 Hatch Cover and Door Interference
Statement: Analysis and Demonstration - Translation paths shall be verified by analysis and demonstration. Analysis shall include identifying suited operation scenarios for crew ingress and egress (nominal and off-nominal) from one vehicle or transfer between two, including the likely pressurization state of suits. Analysis shall consist of using high-fidelity computer graphic models. The models shall include the vehicles, suited crewmembers, and suited crewmembers' movement through the translation paths. The demonstration shall occur in a high-fidelity mockup in 1 g in the flight configuration with integrated GFE, stowage, vehicle installations, and closeouts installed. The demonstration shall consist of suited subjects performing ingress and egress (nominal and off-nominal) operation scenarios.

Verification Success Criteria: The verification shall be considered successful when the analysis and demonstration show that suited ingress and, egress (nominal and off-nominal) operations can be performed without being hampered by protrusions and snag points.

DVO-HLS-HMTA-0180 Hatch Cover Closure and Latching Status Indication
Statement: Demonstration - Hatch closure and open status shall be verified by demonstration. The demonstration shall occur in a qualification vehicle or a high-fidelity mockup. The demonstration shall consist of the following tasks: opening the hatch and identifying that the hatch closure status indicates that the hatch is open and closing the hatch and identifying that the hatch closure status indicates that the hatch is closed.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows that the hatch closure and open status is displayed from each side of each hatch.

DVO-HLS-HMTA-0181 Hatch Cover Pressure Indication
Statement: Demonstration - Pressure difference measurement shall be verified by demonstration. The demonstration shall occur in the vehicle or high-fidelity mockup. The demonstration shall consist of one subject performing the pressure difference measurement on both sides of each hatch under the range of expected internal/external pressure levels. The verification shall be considered successful when the demonstration shows that all pressure differences are measured on each side of the vehicle.

DVO-HLS-HMTA-0182 Restraints
Statement: Inspection - Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 8033, 8034, 8037 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0183 Crew Restraint Provision
Statement: Analysis and Inspection - Crew Restraint Provision shall be verified by analysis and inspection. A task analysis shall be performed to identify tasks requiring operator stability and translation activities in the applicable mission phases and environments. The inspection shall consist of a review of engineering drawings, 3D CAD models, and identified locations of mission tasks and translation paths. [taken from CCT-REQ-1130]

Verification Success Criteria: The verification shall be considered successful when the inspection shows that restraint and mobility aid placement and design accommodate motions and body posture of the crew in their flight configuration required for the task. [taken from CCT-REQ-1130]

DVO-HLS-HMTA-0184 Crew Restraint Design

Statement: Analysis and Inspection - Crew Restraint Design shall be verified by analysis and inspection. A task analysis shall be performed to identify tasks requiring operator stability and translation activities in the applicable mission phases and environments. The inspection shall consist of a review of engineering drawings, 3D CAD models, and identified locations of mission tasks and translation paths. [taken from CCT-REQ-1130]

Verification Success Criteria: The verification shall be considered successful when the inspection shows that restraint and mobility aid placement and design accommodate motions and body posture of the crew in their flight configuration required for the task. [taken from CCT-REQ-1130]

DVO-HLS-HMTA-0187 Crew Restraints for Controls Operation

Statement: Analysis and Inspection - Crew Restraint for Controls Operation shall be verified by analysis and inspection. A task analysis shall be performed to identify tasks requiring operator stability and translation activities in the applicable mission phases and environments. The inspection shall consist of a review of engineering drawings, 3D CAD models, and identified locations of mission tasks and translation paths. [taken from CCT-REQ-1130]

Verification Success Criteria: The verification shall be considered successful when the inspection shows that restraint and mobility aid placement and design accommodate motions and body posture of the crew in their flight configuration required for the task. [taken from CCT-REQ-1130]

DVO-HLS-HMTA-0189 Mobility Aids - Initial

Statement: Inspection - Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 8039, 8040, 8041, 11003 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0191 Mobility Aid Structural Strength

Statement: Analysis and Test - The structural integrity of crew interfaces shall be verified by analysis and test. An analysis shall determine the type of strength by which the crew would apply loads to the crew interfaces in nominal and off-nominal tasks. Crew interfaces shall be load tested to the levels in the Physical Characteristics and Capabilities Data Set provided by NASA for those types of strength (taken from CCT-REQ-1130).

Verification Success Criteria: The verification shall be considered successful when the test shows that the interfaces can withstand maximum crew operation loads as

defined in the Physical Characteristics and Capabilities Data Set provided by NASA (taken from CCT-REQ-1130).

DVO-HLS-HMTA-0192 Mobility Aid for Assisted Ingress and Egress
Statement: Inspection - Mobility aids for ingress and egress (nominal and off-nominal) shall be verified by inspection. The inspection shall consist of a review of engineering drawings and ingress and egress translation paths.

Verification Success Criteria: The verification shall be considered successful when the inspection shows that restraint placement allows for ingress and egress (nominal and off-nominal).

DVO-HLS-HMTA-0193 Unassisted Ingress, Egress and Escape Mobility Aids
Statement: Inspection - Mobility aids for ingress and egress (nominal and off-nominal) shall be verified by inspection. The inspection shall consist of a review of engineering drawings and ingress and egress translation paths.

Verification Success Criteria: The verification shall be considered successful when the inspection shows that restraint placement allows for ingress and egress (nominal and off-nominal).

DVO-HLS-HMTA-0195 Mobility Aid Provision for Suited Operations
Statement: Analysis and Inspection - Mobility Aid Provision for Suited Operations shall be verified by analysis and inspection. A task analysis shall be performed to identify tasks requiring suited operator stability and translation activities in the applicable mission phases and environments. The inspection shall consist of a review of engineering drawings, 3D CAD models, and identified locations of mission tasks and translation paths. [taken from CCT-REQ-1130]

Verification Success Criteria: The verification shall be considered successful when the inspection shows that restraint and mobility aid placement and design accommodate motions and body posture of the suited crew in their flight configuration required for the task. [taken from CCT-REQ-1130]

DVO-HLS-HMTA-0196 Viewing Exterior Operations - Initial
Statement: Inspection, Analysis, and Demonstration - The provision of an external observation window shall be verified by inspection of the engineering drawings and data packs for the lead flight article, followed by inspection of engineering drawings and data packs only for subsequent articles. The functionality of the external observation window shall be verified by analysis and demonstration. The verification shall be considered successful when the inspection shows that a window has been provided for external observation and that the analysis and demonstration show that the system window provides the optical characteristics and field-of-view appropriate to its tasking per JSC 63307, Requirements for Optical Properties for Windows Used in Crewed Spacecraft.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0199 Window Light Blocking
Statement: Demonstration - Window Light Blocking shall be verified by demonstration. The demonstration shall utilize a flight representative vehicle in the flight configuration with representative sunlight on the vehicle and glare control in place. [taken from CCT-REQ-1130]

Verification Success Criteria: The verification shall be considered successful when the demonstration shows that the displays are legible and windows for viewing tasks are free of glare. [taken from CCT-REQ-1130]

DVO-HLS-HMTA-0201 Spacecraft Lighting - Initial
Statement: Inspection - Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 8051, 8052, 8053, 8056, 8058 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0202 Illumination Levels
Statement: Analysis and Test - Light levels shall be verified by both analysis and test. Verification by analysis consists of a lighting/raytraced photometric model that represents the architecture, surface reflectance, and light source beam patterns with their optics considered. The model provides a method to review a range of human factors metrics including light level (horizontal, vertical, surface), and uniformity/glare. To reduce risk, the analysis method should be performed prior to finalizing a design to check for architectural, beam pattern, and system design issues. Once the flight vehicle is built, verification should be completed by physical test with a spectral irradiance meter. The spectral irradiance meter will provide both color and spectrum data that will reduce calibration errors on the estimate of photopic light levels. All physical measurements taken with a sensor shall have location and orientation documented with respect to the habitat along with documentation of issues such as the presence of the test conductor within the measurement field. Lighting intensities shall comply with agreed upon general and specific task illumination requirements specific to the architecture

Verification Success Criteria: Testing in the flight-like vehicle or high-fidelity mockup with representative tasks and hardware is necessary to validate the task analysis to identify lighting requirements per location, to determine potential interference and shadowing due to deployed hardware and operators, and to ensure that the lighting

configuration is responsive to dynamic crew tasks and vehicle reconfiguration. Because not all tasks will be defined with high fidelity prior to vehicle design, general illumination must be accommodated at most vehicle locations to ensure task performance and flexibility. Portable lights may be used to supplement general and task lighting for off-nominal activities such as behind-the-panel maintenance but cannot be considered in vehicle lighting configurations for verification of tasks in the nominal configurations of the vehicle.

DVO-HLS-HMTA-0203 Exterior Lighting
Statement: Analysis, Inspection, and Test - Because of the complicated nature of the requirement, verification shall be accomplished by analysis of integrated human/machine/vision tasks planned for the exterior environment to identify critical lighting constraints, Inspection of drawings and operational flight rules regarding operations requiring visual feedback as part of the mission success criteria, and Test of critical visual systems with flight like orbital and artificial lighting conditions to validate system interfaces.

DVO-HLS-HMTA-0204 Emergency Lighting
Statement: Analysis, Test, and Demonstration - The emergency lighting system shall be verified by analysis, test and demonstration. A task analysis shall determine the operations required for operational recovery and crew egress and the task surfaces required to support those operations. The test shall evaluate task surfaces required for operational recovery and emergency crew egress paths in a flight representative vehicle in the flight configuration. The test shall perform illumination measurements made on and normal to the task surface(s) with a subject positioned to perform the operational tasks, including egress. The test shall evaluate automatic activation of emergency lighting by interrupting primary vehicle power and measuring elapsed time to activation of emergency lighting. For unpowered emergency illumination sources, a demonstration shall be performed with the spacecraft emergency egress configuration. The verification shall be considered successful when test shows that emergency lighting can be automatically activated and illumination levels support operational recovery activities and the demonstration shows that unpowered emergency illumination sources support crew egress.

DVO-HLS-HMTA-0207 Circadian Entrainment
Statement: Analysis and Inspection - Circadian Entrainment shall be verified by analysis and inspection of drawings

DVO-HLS-HMTA-0208 Lighting Controls
Statement: Demonstration - Operation of the On/Off control to prevent and restore light emission by the lights shall be verified by demonstration. The demonstration shall consist of turning the On/Off control to the Off condition and subsequent observation of the controlled light by an observer who has been dark adapted for at least 20 minutes, followed by returning the control to the On condition. The demonstration shall be deemed successful if the Off condition of the control is evident by touch or sight,

the adapted observer detects no visible light emanating from the light source with the control in the Off condition, and selection of the On condition of the control reactivates the light.

DVO-HLS-HMTA-0210 Uniformity, Glare, & Shadows
Statement: Demonstration - Uniformity, Glare, & Shadows shall be verified by demonstration. The demonstration shall utilize a flight representative vehicle in the flight configuration with representative sunlight on the vehicle and glare control in place. [taken from CCT-REQ-1130]

Verification Success Criteria: The verification shall be considered successful when the demonstration shows that the displays are legible and windows for viewing tasks are free of glare. [taken from CCT-REQ-1130]

DVO-HLS-HMTA-0211 Mechanical Hazard - Initial
Statement: Inspection - Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 9005, 9006, 9007, 9008, 9027 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0212 Entrapment
Statement: Analysis and Demonstration - The protection of crew from entrapment shall be verified through analysis and demonstration. An analysis shall be performed to identify potential sources for entrapment and their designed control measures. Demonstration of crew motion restraints shall be performed using flight representative retention systems to verify that crewmembers are able to release fasteners under simulated nominal and emergency conditions. (taken from CCT-REQ-1130)

Verification Success Criteria: The verification shall be considered successful when analysis and demonstration show that potential entrapment sources are controlled (reference Sections 6.3.3.4 and 6.3.3.5 of SSP 50005) and that crew can release from motion restraints. (taken from CCT-REQ-1130)

DVO-HLS-HMTA-0213 Potential Energy
Statement: Analysis - The protection of crew from stored potential energy shall be verified through analysis. An analysis shall be performed to identify stored potential energy sources and their designed control measures. (taken from CCT-REQ-1130)

Verification Success Criteria: The verification shall be considered successful when the analysis shows that stored potential energy sources are inaccessible to crew or have acceptable control measures to prevent injury. (taken from CCT-REQ-1130)

DVO-HLS-HMTA-0214 Protection from Projectiles and Structural Collapse
Statement: Analysis and Test - Protection from Projectiles and Structural Collapse shall be verified by test and analysis.

DVO-HLS-HMTA-0215 Protection
Analysis and Test - The structural integrity of crew interfaces shall be verified by analysis and test. An analysis shall determine the type of strength by which the crew would apply loads to the crew interfaces in nominal and off-nominal tasks. Crew interfaces shall be load tested to the levels in the Physical Characteristics and Capabilities Data Set provided by NASA for those types of strength (taken from CCT-REQ-1130).

Verification Success Criteria: The verification shall be considered successful when the test shows that the interfaces can withstand maximum crew operation loads as defined in the Physical Characteristics and Capabilities Data Set provided by NASA (taken from CCT-REQ-1130).

DVO-HLS-HMTA-0222 High-Temperature Exposure
Statement: Analysis and Test - High-Temperature Exposure shall be verified by test and analysis. Test shall be conducted to measure temperature of hot surfaces that are exposed to crew contact. Where TES > 45ºC (113ºF), an analysis shall be performed to determine maximum TPM for those exposed surfaces. [taken from CCT-REQ-1130]

Verification Success Criteria: The verification shall be considered successful when test and/or analysis show that temperatures for exposed surfaces are lower than TPM and appropriate hazard control measures are implemented.
TPM shall be calculated as follows [taken from CCT-REQ-1130]:
When calculating TPM for intentional contact, a minimum time of 10 seconds applies. Where contact time for nominal operations is planned to exceed 10 seconds, time increments for up to 30 seconds, up to 60 seconds, or infinite time are to be used. Because contact time is a factor in establishing permissible material temperature, consider the following if there is potential for exceeding planned contact time:
Either calculate TPM using higher or infinite contact time, especially if there may be an adverse consequence due to unplanned release of an object, or
Inform crewmembers of the contact time limit via an operational control that has been coordinated with the operations community.
The equation for TPM assumes the object material is homogeneous. If the object is a layup of different materials (i.e., is comprised of layers), TPM is to be calculated using the thermophysical properties of the material with lowest value for inverse thermal inertia. Alternately, with justification, TPM may be calculated using the thermophysical properties of the material in the layup that is the largest contributor to the change in skin temperature. Refer to the NASA/SP-2010-3407, Human Integration Design Handbook (HIDH) for additional guidance on calculating TPM.

Figure Q.2.2V-1 illustrates hot TPM for incidental and intentional (planned) contact and four common materials.

1. For *incidental* contact, defined as contact time $t \leq 1$ second:

$$T_{PM}\ (°C) = a * (k\rho c)^{-1/2} + b$$

Where:

$(k\rho c)^{-1/2}$ = inverse thermal inertia of material (cm^2 °C $sec^{1/2}$)/cal (Table Q.2.2V-1)
a = 0.92
b = 69.97

2. For *intentional* contact, defined as planned skin contact for any length of time:

$$T_{PM}\ (°C) = a * (k\rho c)^{-1/2} + b$$

Where:

$(k\rho c)^{-1/2}$ = inverse thermal inertia of material (cm^2 °C $sec^{1/2}$)/cal (Table Q.2.2V-1)
a, b = constants in Table Q.2.2V-2 Hot Temperature Constants for Intentional (Planned) Contact

Table Q.2.2V-1: Inverse Thermal Inertia for Commonly Used Materials

Material	Inverse Thermal Inertia $(k\rho c)^{-1/2}$ ((cm^2 °C $sec^{1/2}$)/cal)
Aluminum (6061T-6)	2.2
316 Stainless Steel	5.9
Glass	28.8
Teflon	57.5
Nylon Hook Velcro	586 (effective)
k = thermal conductivity, ρ = density, c = specific heat	

Table Q.2.2V-2: Hot Temperature Constants for Intentional (Planned) Contact

Contact Time (s)	a	b
10	0.48	50.07
30	0.46	46.61
60	0.45	45.90
∞	0.42	44.87
Note: for intentional contact, a minimum time of 10 seconds applies when calculating T_{PM}.		

DVO-HLS-HMTA-0223 Low-Temperature Exposure

Statement: Analysis and Test - Low-Temperature Exposure shall be verified by test and analysis. Test shall be conducted to measure temperature of cold surfaces that

are exposed to crew contact. Where TES ≤ 0ºC (32ºF), analysis shall be performed to determine the minimum TPM for those exposed surfaces. [taken from CCT-REQ-1130]

Verification Success Criteria: The verification shall be considered successful when test and/or analysis show that temperatures for exposed surfaces are higher than TPM and appropriate hazard control measures are implemented.
TPM shall be calculated as follows [taken from CCT-REQ-1130]:
When calculating TPM for intentional contact, a minimum time of 10 seconds applies. Where contact time for nominal operations is planned to exceed 10 seconds, time increments for up to 30 seconds, up to 60 seconds, or infinite time are to be used. Because contact time is a factor in establishing permissible material temperature, consider the following if there is potential for exceeding planned contact time:
 Either calculate TPM using higher or infinite contact time, especially if there may be an adverse consequence due to unplanned release of an object, or
 Inform crewmembers of the contact time limit via an operational control that has been coordinated with the Operations community.
The equation for TPM assumes the object material is homogeneous. If the object is a layup of different materials (i.e., is comprised of layers), TPM is to be calculated using the thermophysical properties of the material with lowest value for inverse thermal inertia. Alternately, with justification, TPM may be calculated using the thermophysical properties of the material in the layup that is the largest contributor to the change in skin temperature. Refer to the NASA/SP-2010-3407, Human Integration Design Handbook (HIDH) for additional guidance on calculating TPM.
Figure Q.2.4V-1 illustrates cold TPM for incidental and intentional (planned) contact and four common materials.
Figure Q.2.4V-1: Cold Temperature Touch Limits

1. For *incidental* contact, defined as contact time $t \leq 1$ second:

$$T_{PM}\,(°C) = a * (k\rho c)^{-1/2} + b$$

Where:

$(k\rho c)^{-1/2}$ = inverse thermal inertia of material (cm^2 °C $sec^{1/2}$)/cal (Table Q.2.2V-1)
a, b = constants in Table Q.2.4V-1 Cold Temperature Constants for Incidental Contact

2. For *intentional* contact, defined as planned skin contact for any length of time:

$$T_{PM}\,(°C) = a * (k\rho c)^{-1/2} + b$$

Where:

$(k\rho c)^{-1/2}$ = inverse thermal inertia of material (cm^2 °C $sec^{1/2}$)/cal (Table Q.2.2V-1)
a, b = constants in Table Q.2.4V-2 Cold Temperature Constants for Intentional (Planned) Contact

Table Q.2.4V-1: Cold Temperature Constants for Incidental Contact

time (s)	$(k\rho c)^{-1/2}$	a	b
1	≤ 43.5	-1.16	0
	> 43.5	-0.88	-12.29

Table Q.2.4V-2: Cold Temperature Constants for Intentional (Planned) Contact

time (s)	a	b
10	-0.71	4.78
30	-0.62	9.51
60	-0.53	10.00
∞	-0.37	10.00
Note: for intentional contact, a minimum time of 10 seconds applies when calculating T_{PM}		

Figure Q.2.4V-1 illustrates cold T_{PM} for incidental and intentional (planned) contact and four common materials. [V.CTS.251]

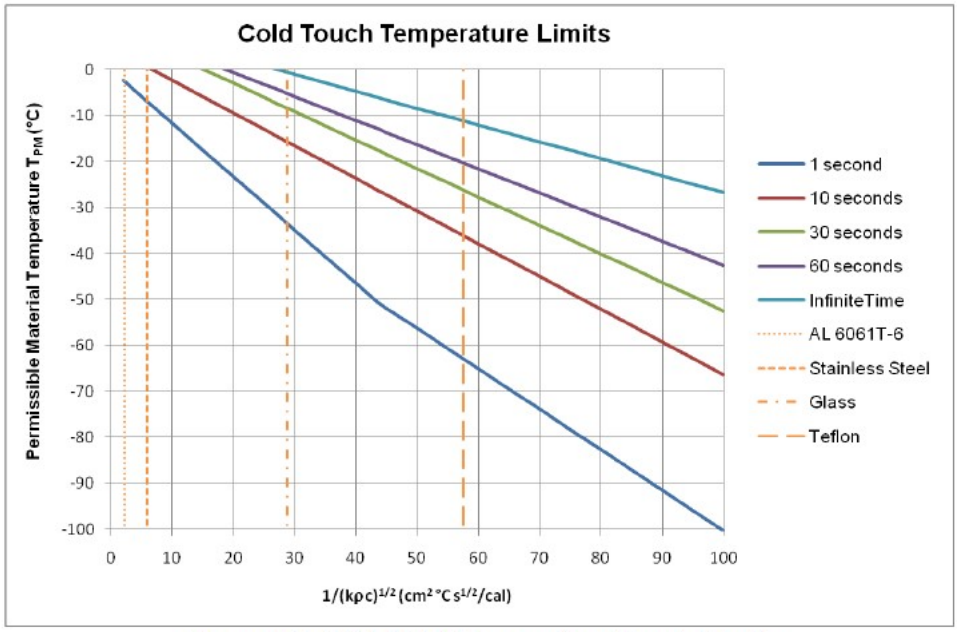


Figure Q.2.4V-1: Cold Temperature Touch Limits

DVO-HLS-HMTA-0225 Electrical Hazard Protection - Initial

Statement: Analysis and Test - Prevention of crew exposure to currents greater than those in HS4008, table Electrical Hazard Potential and table Let-Go Current shall be verified by analysis and test. The analysis shall determine the locations where the crew may be exposed to electrical currents. The analysis shall identify controls at the locations where currents are greater than those provided in the tables. The test shall measure the electrical current at each of the locations as identified in the analysis. The verification shall be considered successful when the analysis and test show that the electrical current measured at each location to which the crew may be exposed is not greater than the current provided in the tables or that the electrical potentials controls are in place. Further, Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 9017, 9018, 9019, 9020, 9021, 9022, 9023 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0226 Power Interruption

Statement: Analysis and Demonstration - Crew interruption of electrical power and confirmation of energized circuits shall be verified by analysis and demonstration. The analysis shall identify locations that could expose IVA crewmembers to voltages in

excess of 32V. The demonstration shall be in the flight vehicle and include a subject demonstrating the ability to interrupt electrical power at the locations identified in the analysis. The analysis and demonstration shall be considered successful when it is shown that the crewmember can interrupt electrical power and confirm the de-energized status of the circuit that could expose crewmembers to voltages in excess of 32V.

Verification Success Criteria: No further rationale is required

DVO-HLS-HMTA-0227 Energized Status
Statement: Analysis and Demonstration - Crew interruption of electrical power and confirmation of energized circuits shall be verified by analysis and demonstration. The analysis shall identify locations that could expose IVA crewmembers to voltages in excess of 32V. The demonstration shall be in the flight vehicle and include a subject demonstrating the ability to interrupt electrical power at the locations identified in the analysis. The analysis and demonstration shall be considered successful when it is shown that the crewmember can interrupt electrical power and confirm the de-energized status of the circuit that could expose crewmembers to voltages in excess of 32V.

Verification Success Criteria: No further rationale is required

DVO-HLS-HMTA-0228 Nominal Physiological Electrical Current Limits
Statement: Analysis and Test - Nominal Physiological Electrical Current Limits shall be verified by test and analysis.

DVO-HLS-HMTA-0229 Catastrophic Physiological Electrical Current Limits for all Circumstances
Statement: Analysis - Catastrophic Physiological Electrical Current Limits for all Circumstances shall be verified by analysis.

DVO-HLS-HMTA-0230 Catastrophic Physiological Electrical Current Limits for Startle Reaction
Statement: Analysis - Catastrophic Physiological Electrical Current Limits for Startle Reaction shall be verified by analysis.

DVO-HLS-HMTA-0230 Body Impedance for Voltage Calculations Utilizing Electrical Current Thresholds
Statement: Analysis - Body Impedance for Voltage Calculations Utilizing Electrical Current Thresholds shall be verified by analysis.

DVO-HLS-HMTA-0232 Leakage Currents – Equipment Designed for Human Contact
Statement: Analysis and Test - The patient-care equipment chassis leakage current requirement shall be verified by test. The test shall consist of measuring the powered-up leakage current at the exposed chassis/enclosure surface of actual patient-care

flight hardware that could come into contact with crew, ground personnel, or patients. The verification shall be considered successful when the test indicates that the chassis leakage current is less than or equal to the associated limit in HS4008C, table Chassis Leakage Current - Patient.

DVO-HLS-HMTA-0233 Minimize Fluid and Gas Spill Hazards - Initial
Statement: Inspection - Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 9024, 9025, 9026 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0417 Fluid/Gas Release
Statement: Analysis - Protection of crew against release of hazardous fluids (liquids or gases) shall be verified through analysis. An analysis shall be performed to identify the hazard severity level of all fluids used in the system and the controls preventing their release.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that controls against release are commensurate with the hazard severity level during all operational phases

DVO-HLS-HMTA-0235 Fluid/Gas Isolation
Statement: Inspection - Fluid isolation features shall be verified by inspection. The inspection shall consist of a review of the engineering drawings for the components and ORUs that contain fluid and require maintenance. The verification shall be considered successful when the inspection shows that the components and ORUs have fluid isolation features.

DVO-HLS-HMTA-0234 Fluid/Gas Containment
Statement: Analysis - Protection of crew against release of hazardous fluids (liquids or gases) shall be verified through analysis. An analysis shall be performed to identify the hazard severity level of all fluids used in the system and the controls preventing their release.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that controls against release are commensurate with the hazard severity level during all operational phases

DVO-HLS-HMTA-0237 Inflight Maintenance and Assembly - Initial
Statement: Inspection - Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 9031, 9032, 9033, 9038, 9047, 9051, 9052 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0239 Connector Actuation without Tools
Statement: Demonstration - Connector Actuation without Tools shall be verified by demonstration.

DVO-HLS-HMTA-0240 Incorrect Mating, Demating Prevention
Statement: Demonstration and Test - Incorrect Mating, Demating Prevention shall be verified by demonstration and test.

DVO-HLS-HMTA-0241 Mating, Demating Hazards
Statement: Analysis - The protection of crew from mate / de-mate hazards shall be verified through hazard analysis. An analysis shall be performed to identify mate / de-mate tasks, any associated exposure risks, and their design control measures.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that the crew is protected against hazardous fluid release, exposure to high energy sources, or other mate / de-mate hazards.

DVO-HLS-HMTA-0246 In-Flight Tool Set
Statement: Inspection - In-Flight Tool Set shall be verified by inspection.

DVO-HLS-HMTA-0247 Maintenance Time
Statement: Analysis - The number of hours for preventive maintenance and housekeeping shall be verified by analysis. The analysis shall determine the total number of hours required for preventive maintenance and housekeeping for the mission duration and average the hours over the mission duration. The verification shall be considered successful when the analysis shows that all preventive maintenance and housekeeping can be accomplished for a mission while requiring no more than an average of two person-hours per day.

DVO-HLS-HMTA-0254 Maintenance Accommodation
Statement: Analysis and Test - Maintenance Accommodation shall be verified by analysis and test.

DVO-HLS-HMTA-0258 Fault Detection
Statement: Demonstration and Test - Fault Detection shall be verified by demonstration and test.

DVO-HLS-HMTA-0259 Failure Notification
Statement: Demonstration - Component failure alert shall be verified by demonstration. The demonstration shall include simulating out-of-tolerance operation

of equipment. The verification shall be considered successful when an alert is detected upon the system's receipt of out-of-tolerance limits.

DVO-HLS-HMTA-0260 Protective Equipment
Statement: Analysis and Inspection- The spacecraft's provision for PPE, including automated PPE, shall be verified through analysis and inspection. An analysis shall be performed to identify potential emergency scenarios and their designed control measures that include crew PPE. There will be an inspection of PPE stowage locations.

Verification Success Criteria: The verification shall be considered successful when the analysis and inspection show that PPE is provided for each crewmember and is accessible by crew for potential emergency events.

DVO-HLS-HMTA-0261 Protective Equipment Use
Statement: Test - Protective Equipment Use shall be verified by test.

DVO-HLS-HMTA-0263 Protective Equipment Automation
Statement: Demonstration and Test - Protective Equipment Automation shall be verified by demonstration and test.

DVO-HLS-HMTA-0264 Use of Hearing Protection
Statement: Inspection - Inspection of compliance with requirements HLS-HMTA-0067, HLS-HMTA-0068, HLS-HMTA-0069, HLS-HMTA-0070, HLS-HMTA-0071, HLS-HMTA-0072, HLS-HMTA-0073, HLS-HMTA-0074, HLS-HMTA-0075, HLS-HMTA-0076, HLS-HMTA-0077, HLS-HMTA-0078, HLS-HMTA-0079, HLS-MTA-0080, HLS-HMTA-0081, and HLS-HMTA-0082 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Success Criteria: This verification shall be complete when inspection confirms HLS compliance to requirements HLS-HMTA-0067 through HLS-HMTA-0082.

DVO-HLS-HMTA-0266 Hearing Protection Interface
Statement: Test - Interference of hearing protection shall be verified through test. Tests shall be performed with operators who have hearing sensitivity that meets flight standards of NASA Crewmembers Medical Standards, Volume 1, without waiver as they wear hearing protection while performing representative in-flight operations with representative flight equipment in operation. Without prompting the operator, simulated alerts shall be triggered and voice communications shall be conducted. The operator will indicate when alerts are heard or respond to voice communications.

Verification Success Criteria: The verification shall be considered successful when tests confirm that hearing protection does not inhibit voice communication or monitoring of the system or alerts.

DVO-HLS-HMTA-0275 Crew Interface Effectiveness

Statement: Analysis and Test - Crew interface usability shall be verified by analysis and test. The analysis shall identify the list of tasks to be performed and the potential errors that can be encountered using standard task analysis methods. The test shall consist of usability evaluations based on standard best practices (e.g., Jacob Nielsen's "Usability Engineering", 1993). During the usability evaluation, a minimum of 20 crewmembers or crew designated representatives will perform a set of NASA-approved onboard tasks in a high-fidelity flight-like simulator or mockup. Usability evaluations should include collection of data such as completion times and ratings on subjective questionnaires that will help differentiate design-induced errors from errors related to human reliability. For the usability evaluation, a task is defined as an activity driven by a procedure. The procedure consists of a series of task steps, where a task step is defined as a single instruction to the crewmember, as is typical of current spaceflight procedures. Each task must be completed; failed or incomplete tasks do not pass verification. Participants should maintain task completion times commensurate with the performance requirements of the particular task. The percentage of erroneous task steps for each participant is calculated by dividing the number of erroneous task steps by the total participants committing each erroneous task step is calculated by dividing the number of participants committing each erroneous task step by the total number of participants and multiplying the result by 100. The verification shall be considered successful when the results of the analysis and test show that the percentage of erroneous task steps per participant is no greater than 5%, and the percentage of participants who committed each erroneous task step is no greater than 10%.

Verification Success Criteria: Although errors are often calculated as averages across participants, the approach used in this verification (calculating errors per participant and per task step) ensures that the number of design-induced errors of every task step and every participant is minimized. The approach puts the emphasis on identifying usability problems, rather than just calculating an overall error rate. When more than 10% of participants commit the same erroneous task step, this indicates a serious design issue. When one or more participants commit more than 5% erroneous task steps across the task, this again could indicate serious design issues. If a single participant commits more than 5% erroneous task steps, this could indicate an issue such as deficiency in training or fatigue. In this case, results should be discussed with NASA. Usability verification can be accomplished along with other verifications in well-planned human-in-the-loop evaluations.

DVO-HLS-HMTA-0280 Units of Measure

Statement: Inspection - The use of SI units of measurement shall be verified through inspection. A sample of drawings (e.g., vehicle and workstation labeling), mission software applications, and operational procedures will be inspected. The verification shall be considered successful when the inspections show that units of measure are presented in SI.

DVO-HLS-HMTA-0284 Consistent Procedures
Statement: Inspection - Consistent Procedures shall be verified by inspection.

DVO-HLS-HMTA-0286 Syntax Distinction
Statement: Test - Syntax Distinction shall be verified by test.

DVO-HLS-HMTA-0289 System Health and Status
Statement: Demonstration - System Health and Status shall be verified by demonstration.

DVO-HLS-HMTA-0293 Control Feedback
Statement: Demonstration - Feedback of crew-initiated control activation shall be verified by demonstration. The demonstration shall consist of simulating crew activation of flight-configuration hardware and software controls. The verification shall be considered successful when the demonstration shows that all control systems provide an indication of crew-initiated control activations.

DVO-HLS-HMTA-0299 Controllability and Maneuverability (Manual Control)
Statement: Analysis and Test - Handling qualities shall be verified by analysis and test. Selected manual control scenarios will be defined via review of potential manual control scenarios and associated manual control modes. Analysis shall be performed to select the manual control scenarios selected for testing and required handling qualities ratings. Manual control scenarios shall be selected based on the following considerations; 1) manual control scenarios necessary to meet Manual Piloting for Docking, 2) catastrophic hazard controls that utilize manual control capabilities as part of their mitigation strategy, and 3) manual control scenarios that are uniquely different or more complex than Manual Piloting for Docking. For each selected scenario, a list of handling quality related tasks will be generated as part of a task analysis. 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 must meet Level 1 (handling quality ratings of 1, 2, or 3). A test shall be conducted for each selected scenario with at least five test subjects trained as pilots for the particular spacecraft being evaluated and trained in Cooper-Harper evaluations. Test subjects shall perform the manual control scenarios in flight configuration in a flight representative cockpit and provide Cooper-Harper evaluations for each task in the scenario. The verification shall be considered successful when the analysis and test show that for each task associated with each of the selected manual control scenarios where manual control is the primary control method or where the automated control system is non-operational, at least 60% of the ratings are Level 1 (handling quality ratings of 1, 2 or 3), while up to 40% may exceed Level 1 with a Level 2 rating (handling quality rating of 4, 5, or 6). For any ratings of 4, 5, or 6 to be considered successful, a consensus must be reached by all of the participants indicating that handling qualities are acceptable. For all other scenarios, at least 80% of the ratings must be Level 1 or 2 (HQR of 1, 2, 3, 4, 5 or 6), while up to 20% may exceed Level 2 with a Level 3 rating (HQR of 7, 8 or 9). For any ratings of 7, 8, or 9 to

be considered successful, a consensus must be reached by all of the participants indicating that handling qualities are acceptable.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0300 Tolerate Inadvertent Operator Action
Statement: Inspection - Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 10027, 10028 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0301 Inadvertent Operation Prevention
Statement: Analysis, Inspection, and Demonstration - Inadvertent operation shall be verified by analysis, inspection and demonstration. An analysis shall identify controls whose inadvertent operation would lead to a catastrophic event or an abort and the appropriate level of protection (i.e. one, two, or more inadvertent actions) required. The analysis shall include all mission phases, including operations planned for response to system failures. The inspection and the demonstration shall be performed using flight-configuration hardware and software. The demonstration shall simulate inadvertent inputs using flight representative hardware and software. The verification shall be considered successful when the demonstration shows an “arm-fire” mechanism or action confirmation for commands using a computer display and when the inspection documents the presence of effective guards, covers, and physical separation from other controls.

Verification Success Criteria: No further rationale is required.

DVO-HLS-HMTA-0302 Inadvertent Operation Recovery
Statement: Analysis, Inspection, and Demonstration - Inadvertent Operation Recovery shall be verified by analysis and demonstration.
A task analysis shall be performed to identify human interactions required for the maintenance, operations and control of the system. A human error analysis (HEA) shall be performed, as defined in NPR 8705.2C, Section 2.3.11 Human Error Analysis. The HEA shall define the source of human errors derived from the tasks, the consequence on the system, and the design and operational controls to mitigate or limit the effects. An inspection of drawings and hardware shall confirm maintenance and operational controls for human error have been incorporated. A demonstration of human system interaction tasks shall be performed with simulated errors utilizing flight representative hardware and software.

DVO-HLS-HMTA-0303 Control for Human Error

Statement: Analysis, Inspection, and Demonstration - The system implementation of human error controls shall be verified by analysis, inspection, and demonstration. A task analysis shall be performed to identify human interactions required for the maintenance, operations and control of the system. A human error analysis (HEA) shall be performed, as defined in NPR 8705.2C, Section 2.3.11 Human Error Analysis. The HEA shall define the source of human errors derived from the tasks, the consequence on the system, and the design and operational controls to mitigate or limit the effects. An inspection of drawings and hardware shall confirm maintenance and operational controls for human error have been incorporated. A demonstration of human system interaction tasks shall be performed with simulated errors utilizing flight representative hardware and software.

The verification shall be considered successful when the inspection shows that design and operational controls have been implemented for those sources of errors identified in the HEA, and the demonstration shows that the mitigation is effective at preventing the error or the system allows the human to detect and correct or recover from the errors.
Further, Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 3006, 5005, 5006, 5007, 5008, 10027, 10028, and 10002 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0304 Design Induced Crew Error

Statement: Analysis and Test - Crew interface usability shall be verified by analysis and test. The analysis shall identify the list of tasks to be performed and the potential errors that can be encountered using standard task analysis methods. The test shall consist of usability evaluations based on standard best practices (e.g., Jacob Nielsen's "Usability Engineering", 1993). During the usability evaluation, a minimum of 20 crewmembers or crew designated representatives will perform a set of NASA-approved onboard tasks in a high-fidelity flight-like simulator or mockup. Usability evaluations should include collection of data such as completion times and ratings on subjective questionnaires that will help differentiate design-induced errors from errors related to human reliability. For the usability evaluation, a task is defined as an activity driven by a procedure. The procedure consists of a series of task steps, where a task step is defined as a single instruction to the crewmember, as is typical of current spaceflight procedures. Each task must be completed; failed or incomplete tasks do not pass verification. Participants should maintain task completion times commensurate with the performance requirements of the particular task. The percentage of erroneous task steps for each participant is calculated by dividing the number of erroneous task steps by the total participants committing each erroneous task step is calculated by dividing the number of participants committing each

erroneous task step by the total number of participants and multiplying the result by 100. The verification shall be considered successful when the results of the analysis and test show that the percentage of erroneous task steps per participant is no greater than 5%, and the percentage of participants who committed each erroneous task step is no greater than 10%.

Verification Success Criteria: Although errors are often calculated as averages across participants, the approach used in this verification (calculating errors per participant and per task step) ensures that the number of design-induced errors of every task step and every participant is minimized. The approach puts the emphasis on identifying usability problems, rather than just calculating an overall error rate. When more than 10% of participants commit the same erroneous task step, this indicates a serious design issue. When one or more participants commit more than 5% erroneous task steps across the task, this again could indicate serious design issues. If a single participant commits more than 5% erroneous task steps, this could indicate an issue such as deficiency in training or fatigue. In this case, results should be discussed with NASA. Usability verification can be accomplished along with other verifications in well-planned human-in-the-loop evaluations.

DVO-HLS-HMTA-0305 Crew Control of Vehicle

Statement: Analysis, Test, and Inspection - Human control of vehicle shall be verified by analysis, test, and inspection. The analysis shall identify the list of control tasks to be performed with an associated simulation of the accuracy/precision/timeliness/workload of human control. During the control testing, a minimum of 20 crewmembers or crew designated representatives will perform a set of NASA-approved onboard control tasks in a high-fidelity flight-like simulator or mockup. Control test shall include collection of objective performance data such as completion times, accuracy, and precision as well as subjective workload measures. The inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 10068, 10069, 5005, 507, 5008, 10002 shall include a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: The verification shall be considered successful when control tests indicate that crew can perform control tasks accurately without undue workload, consistent with NASA-STD-3001.

DVO-HLS-HMTA-0307 Control Identification

Statement: Test - Distinguishability of out-of view controls shall be verified by test. The test shall consist of suited and seated operators using the out-of-view controls in a range of assigned control tasks.

Verification Success Criteria: The verification shall be considered successful when the test shows that the operators correctly distinguished the out-of-view controls during the tasks such that there is 95% confidence that operators will make less than 1% erroneous control selections.

DVO-HLS-HMTA-0308 Emergency Control Coding
Statement: Inspection - Coding for emergency controls shall be verified by inspection. The inspection shall involve all controls on the list of emergency controls as defined in a NASA-approved task analysis. The inspection shall include a review of the CSV Labeling Plan and determine whether coding is compliant with the emergency coding defined therein. Testing shall require crew, or representatives with same training, to characterize presentation of each control as for emergency or non-emergency use.

Verification Success Criteria: The verification shall be considered successful when the inspection shows that coding meets the emergency coding defined in the CSV Labeling Plan, and that crew can successfully distinguish whether a control is for emergency v. non-emergency use in a timely manner (1s for emergency controls).

DVO-HLS-HMTA-0319 Command Confirmation
Statement: Demonstration - Command Confirmation shall be verified by demonstration.

DVO-HLS-HMTA-0326 Information Design - Initial
Statement: Inspection - Availability of Environmental Hazards Information shall be verified by inspection.

Verification Success Criteria: Verification shall be considered successful when the inspection shows that the crew has access to environmental hazards information available under simulated flight conditions.

DVO-HLS-HMTA-0342 Measurement Units
Statement: Inspection - Presentation of measurement units associated with datum and groups of data shall be verified by inspection of display formats and in the CSV Display Standard.

DVO-HLS-HMTA-0348 Sound Pressure Level
Statement: Test - Sound Pressure Level shall be verified by test.

DVO-HLS-HMTA-0349 Sound Distortion Level
Statement: Test - Sound Distortion Level shall be verified by test.

DVO-HLS-HMTA-0350 Information Management Capabilities – Provision
Statement: Analysis and Test - The data fidelity requirement shall be verified by analysis and test. The analysis shall determine the data fidelity required for a given task. The test shall be performed on a flight-configuration workstation using flight-configuration software loads. The data fidelity required for each task will be assessed. The verification shall be considered successful when the test shows that the data have been acquired with the fidelity specified by the analysis.

Verification Success Criteria: The data necessary for proper performance of all crew and ground personnel tasks for a given mission shall be determined by a task analysis.

DVO-HLS-HMTA-0356 Information Management Security
Statement: Inspection - Information Management Security shall be verified by inspection.

DVO-HLS-HMTA-0360 Information Backup and Restoration
Statement: Demonstration - Information Backup and Restoration shall be verified by demonstration.

DVO-HLS-HMTA-0361 Alternative Information Sources
Statement: Demonstration - Alternative Information Sources shall be verified by demonstration.

DVO-HLS-HMTA-0362 Software System Recovery
Statement: Test - Software System Recovery shall be verified by test.

DVO-HLS-HMTA-0363 Communication System Design
Statement: Analysis and Test - Communication System Design shall be verified by test and analysis.

DVO-HLS-HMTA-0364 Communication Capability
Statement: Demonstration - Communication Capability shall be verified by demonstration.

DVO-HLS-HMTA-0365 Communication Speech Levels
Statement: Test - Communication Speech Levels shall be verified by test.

DVO-HLS-HMTA-0371 Speech Intelligibility
Statement: Analysis and Test - Speech Intelligibility shall be verified by test and analysis.

DVO-HLS-HMTA-0372 Private Audio Communication
Statement: Demonstration - The system's two-way private voice communication shall be verified by demonstration. The demonstration shall be an integrated demonstration and shall consist of communications between the vehicle and Mission Control Center (MCC) flight control team positions using flight-like avionics. The verification shall be considered successful when the demonstration shows that audio transmitted between the vehicle and the Mission Control Center can only be heard in the vehicle and at the designated flight control team positions.

Verification Success Criteria: Mission Systems will be responsible for providing the two-way private voice communication during the various mission phases.

DVO-HLS-HMTA-0379 Caution & Warning (C&W) Annunciation - Initial
Statement: Inspection - Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 10055, 10056, 10057. 10058, 10059, 10114, 10015, 10016, 10017, 10018, 10019 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0380 Distinguishable and Consistent Alarms
Statement: Test - Distinguishable and Consistent Alarms shall be verified by test.

DVO-HLS-HMTA-0381 Audio Display Sound Level
Statement: Test - The loudspeaker non-speech auditory annunciation levels shall be verified by test. The measurements shall be made within the vehicle in the flight configuration with integrated GFE, stowage, vehicle installations, and closeouts installed. Hardware shall be operated across the expected range of operational settings (including settings corresponding to the expected highest noise levels). The verification shall be considered successful when the test indicates that, for each temporal component of the annunciation, the level is more than the above the ambient noise level at each expected work and sleep station location

Verification Success Criteria: No further rationale is required.

DVO-HLS-HMTA-0382 Reverberation Time
Statement: Analysis and Test - The reverberation time limit shall be verified by test and analysis. Field testing shall be used to measure the reverberation time inside the actual flight vehicle. The methodology given in ISO 3382, "Measurement of the Reverberation Time of Rooms with Reference to Other Acoustical Parameters," shall be used. The test and analysis shall be considered successful when the reverberation time is less than 0.6 second in the 500-Hz, 1-kHz, and 2-kHz octave bands.

Verification Success Criteria: Intermediate testing and analysis should be performed and reviewed by NASA to ensure confidence that compliance with this requirement will be met and to preclude late impacts to cost, schedule, and hardware

DVO-HLS-HMTA-0383 Frequency
Statement: Analysis and Test - Frequency shall be verified by test and analysis.

DVO-HLS-HMTA-0384 Auditory Alarms for Sleeping Crewmembers
Statement: Test - The loudspeaker non-speech auditory annunciation levels shall be verified by test. The SPL measurements for this verification shall be made at the approximate crew sleep head locations using the actual flight equipment (each

serialized unit), installed in the actual flight vehicle in its final configuration with all closeouts installed. SPL measurements shall be made using a Type 1 integrating-averaging sound level meter. The maximum A-weighted SPL (LAmax) with a fast (125 ms) exponentially weighted time averaged response shall be measured.

Objective: Serialized units must be verified individually because of reverberation effects inside the vehicle. Noise attenuation gained by the use of hearing protection is not to be considered toward the compliance of this requirement because hearing protection may not always be worn. Intermediate testing and analysis should be performed and reviewed by NASA to ensure confidence that compliance with this requirement will be met and to preclude late impacts to cost, schedule, and hardware.

Verification Success Criteria: The verification shall be considered successful when field testing indicates that the signal-to-noise ratio is equal to or greater than 15 dBA.

DVO-HLS-HMTA-0385 Visual and Audio Annunciations
Statement: Analysis, Test and Demonstration - Distinctiveness of alert annunciations and visual indications shall be verified by demonstration, analysis and test. The demonstration shall be performed on all non-speech audio annunciations and visual indications using a flight-configuration system to annunciate the signals. Signal content will be compared to Appendix [G], Alert Annunciation. The verification shall be considered successful when the demonstration shows that all non-speech audio annunciations and visual indications meet the Appendix [G], Alert Annunciation. HITL testing is required to ensure that operators are able to correctly distinguish between annunciations and visual indications.

Verification Success Criteria: No further rationale is required.

DVO-HLS-HMTA-0386 Set-Point Alerts
Statement: Analysis - This is verified by analysis, ensuring that set-point control and display capabilities are available for all subsystem parameters for which they are appropriate. HITL testing is required to ensure that the manner in which they do so is comprehensible by crew and supports effective and efficient monitoring, decision-making, diagnosis and action. Effectiveness and efficiency shall be assessed by subjective (SUS) and objective measures.

DVO-HLS-HMTA-0387 Audio Annunciation Silencing
Statement: Demonstration - The crew's ability to silence an audible alarm that would otherwise annunciate continuously shall be verified by demonstration. 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. There are well-known instances of aircraft crews that have been functionally incapacitated by audible alarms that they could not cancel. The inclusion of this requirement is supported by a recommendation from NASA SP-2008-565. However, operators also silence alarms to reduce the

complexity at the moment and fail to subsequently investigate and update situation awareness of degraded systems. As such, the program shall consider those alarms that require realerting and the realert interval when unresolved. The manual control to initiate a system-wide alert shall be verified by demonstration in flight-ready hardware and software, and the detection threshold for this shall be verified in accord with 10.3.4.4 (Speech Intelligibility), 10.3.4.5 (Sleeping Crew Notifications).

DVO-HLS-HMTA-0388 Visual and Auditory Annunciation Failures
Statement: Test - Notification of system failure of visual or auditory annunciators shall be verified by test. The test shall be performed with flight-configuration software and hardware. The test shall run a scenario that simulates failures of the visual and auditory annunciator systems.

Verification Success Criteria: The verification shall be considered successful when the test shows that the vehicle provides notification of either auditory or visual annunciator system failure.

DVO-HLS-HMTA-0389 Visual Alerts - Red
Statement: Inspection - Visual Alerts - Red shall be verified by inspection.

DVO-HLS-HMTA-0390 Visual Alerts - Yellow
Statement: Inspection - Visual Alerts - Yellow shall be verified by inspection.

DVO-HLS-HMTA-0391 Label Provision
Statement: Inspection - The labeling of crew interfaces shall be verified through inspection. A comprehensive inspection of task-analysis-derived labeling requirements vs. documented labels in the CSV Labeling plan shall be conducted. A consistency analysis shall be conducted to ensure that labels, display formats, and OpNom are consistent. A comprehensive inspection shall be conducted to ensure that these required labels are designed and placed appropriately to support task performance. The verification shall be considered successful when these inspections show that crew interfaces are identified with the required labeling, and these are consistent with the OpsNom and Display Format Standard. Further, Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 10060, 7069 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0399 Labeling of Hazardous Waste
Statement: Analysis and Inspection - The labeling of hazardous waste shall be verified by analysis and inspection. Analysis shall identify and characterize hazardous trash toxicity levels in accordance with JSC-26895, Guidelines for Assessing the Toxic

Hazard of Spacecraft Chemicals and Test Materials. Label and trash container drawings will be inspected to verify that hazard labels are implemented.

Verification Success Criteria: The verification shall be considered successful when inspection shows that waste hazard type and toxicity level have been characterized and hazardous waste containers are labeled in accordance with JSC-26895, Guidelines for Assessing the Toxic Hazard of Spacecraft Chemicals and Test Materials.

DVO-HLS-HMTA-0400 Automated and Robotic System Provision
Statement: Demonstration and Inspection - This would be verified by demonstration. Human/Automation and Human/Robotic task allocation must be designed with not only consideration for what is possible to automate, but what the implications of automated/robotic allocation are. Effective h/a and h/r task allocation should test the effects on crew and ground user situation awareness. Further, Inspection of compliance with NASA-STD-3001 Vol 2, Rev B Requirement(s) 10100, 10105, 10109, 10110 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA.

DVO-HLS-HMTA-0398 Automated and Robotic System Design
Statement: Demonstration and Test - This requirement would be verified by demonstration and test.

DVO-HLS-HMTA-0404 Automation Level Status Indication
Statement: Demonstration and Test - This requirement would be verified by demonstration and test.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA. Each mode will need hardware and software testing as well as a defined failure response and notification messages if the expected mode was not achieved.

DVO-HLS-HMTA-0407 Automated and Robotic System Operation – with Communication Limitations
Statement: Demonstration and Test - This requirement would be verified by demonstration and test.

DVO-HLS-HMTA-0408 Automation and Robotics Shut Down Capabilities
Statement: Demonstration and Test - This requirement would be verified by demonstration and test.

Objective: Verify that the hardware (any switches/lights) and software work together to successfully interrupt various robotic processes to shut down the system.

Verification Success Criteria: Success is defined when any and all modes of operation can be shut down in a timely manner. If the shutdown is built with redundancy, test that each path works.

DVO-HLS-HMTA-0409 Automation and Robotics Override Capabilities
Statement: Demonstration and Test - This requirement would be verified by demonstration and test.

Objective: Verify that the hardware (any switches/lights) and software work together to successfully interrupt various robotic processes to override the system.

Verification Success Criteria: Success is defined when any and all modes of operation can be overridden in a timely manner. If the override is built with redundancy, test that each path works.

DVO-HLS-HMTA-0412 Reusability of Habitable Vehicles (sustainability)
Statement: Analysis and Demonstration - The reusability of vehicles shall be verified by analysis and demonstration

DVO-HLS-HMTA-0440 Average Feces per Day
The collection and containment of fecal matter shall be verified by demonstration and analysis. The demonstration shall be performed with flight-like hardware to show containment independent of gravity. The demonstration shall consist of a release into the collection system, followed by a repeated release into the collection system. The analysis shall determine the volume of the collection system.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that 150 g and 150 mL of fecal matter per crewmember per defecation at an average of two defecations per day are contained.

DVO-HLS-HMTA-0416 Maximum Feces per Event
The collection and containment of fecal matter shall be verified by demonstration and inspection. The inspection shall determine the volume of the collection system. The demonstration shall occur in an analogous gravity environment with flight-like hardware. The demonstration shall consist of a release into the collection system.

Verification Success Criteria: The verification shall be considered successful when the inspection and demonstration show that the collection system can hold 500 g

and 500 mL of fecal matter per crewmember, release can be collected, and release is contained.

DVO-HLS-HMTA-0442 Maximum Diarrhea per Event

The per-event collection and containment of diarrhea discharge shall be verified by demonstration and analysis. The analysis shall determine the volume of the collection system. The demonstration shall be performed with flight-like hardware to show containment independent of gravity. The demonstration shall consist of a release into the collection system.

Verification Success Criteria: The verification shall be considered successful when the analysis and demonstration show that the collection system can hold 1.5 L of diarrheal discharge in a single event, each release can be collected with no spillage or leakage, and each release is contained.

DVO-HLS-HMTA-0418 Urine Capacity

The collection and isolation of urine shall be verified by inspection. The inspection shall determine the volume of the collection system.

Verification Success Criteria: The verification shall be considered successful when the inspection shows that the collection system can collect and isolate from the crew environment the amount of urine specified by the equation per crewmember for the duration of the mission.

DVO-HLS-HMTA-0419 Urine per Crewmember

The collection and isolation of urine shall be verified by inspection. The inspection shall determine the volume of the collection system.

Verification Success Criteria: The verification shall be considered successful when the inspection shows that the collection system can collect and isolate from the crew environment the amount of urine specified by the equation per crewmember for the duration of the mission.

DVO-HLS-HMTA-0420 Urine Rate

The collection and isolation of urine shall be verified by inspection. The inspection shall determine the volume of the collection system.

Verification Success Criteria: The verification shall be considered successful when the inspection shows that the collection system can collect and isolate from the crew environment the amount of urine specified by the equation per crewmember for the duration of the mission.

DVO-HLS-HMTA-0421 Urine and Menses Elimination Concurrence

The collection and isolation of menses and urine shall be verified by inspection. The inspection shall determine the volume of the collection system.

Verification Success Criteria: The verification shall be considered successful when the inspection shows that the collection system can collect and isolate from the crew environment the amount of menses and urine specified by the equation per crewmember for the duration of the mission.

DVO-HLS-HMTA-0424 Medical Equipment Usability

The medical equipment usability shall be verified by test.

Verification Success Criteria: The test shall be considered successful when all medical hardware can be shown to have a successful result on a System Usability Scale evaluation as defined in HMTA-0274.

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DVO-HLS-HMTA-0429 Individual Medical Accessory Kit

The Individual Medical Accessory Kit shall be verified by analysis

Verification Success Criteria: The analysis shall be considered successful when adequate mass and volume are shown to be allocated to these kits.

Appendix D Design and Construction Standards

This Appendix provides detailed design and construction standards. These standards are proven methods to improve safety when applied. These are the standards that NASA would apply if it were to design, build, certify, and operate an HLS. They are offered in this document as a starting point for the Offeror's proposal for all work to be performed through the end of the contract. The Offeror's proposal shall:

(1) Demonstrate that the proposal meets or exceeds each NASA standard

(2) Employ an alternative approach to a specific standard which the Offeror asserts is equivalent in outcome, with a thorough explanation of such equivalency and a rationale in support of this approach in lieu of NASA's specification (i.e., a "meets the intent of" approach); and/or

(3) On a case-by-case basis, provide an approach that does not meet a particular NASA standard or its intent, but results in a demonstrably better approach that is more likely to enable the Offeror's ability to achieve one or more of NASA's overarching objectives and functional performance requirements as set forth in section 3 and 4 of this document.

D.1 Safety Design and Construction

HLS-SMA-0017 Parts Policy

The HLS shall meet the intent of NPD 8730.2C , NASA Parts Policy, chapters 1, 5.e, and 5.f.1 -5.f.5* (The authority to approve waivers to these requirements remains at the HQ OSMA level and cannot be delegated.), 5.f.6, Attachment B, and Attachment C for all parts on board the HLS.

Rationale: It is NASA policy to control risk and enhance reliability in NASA flight and critical ground support/test systems, in part, by managing the selection, acquisition, traceability, testing, handling, packaging, storage, and application of the following:

(1) Electrical, electronic, and electromechanical (EEE) parts.
(2) Electronic packaging and interconnect systems.
(3) Mechanical parts such as fasteners, bearings, studs, pins, rings, shims, piping components, valves, springs, brackets, clamps, and spacers.
(4) Manufacturing materials affecting the performance/acceptability of parts such as plating, solder, and weld filler material.

Implementing the elements of this policy enhances the HLS reliability. Special consideration should be applied to Appendix C dealing with counterfeit mechanical parts and materials to ensure the accuracy of the reliability data sets.

HLS-SMA-0018 General Safety Program

The HLS shall meet the intent of NPR 8715.3D, NASA General Safety Program Requirements, sections 1.7.4.2.a, 1.7.4.2.f-h, 3.15.7 - 3.15.8 (in-flight lasers and laser operations), 6** (if radioactive material is to be flown) to implement and manage a comprehensive safety program.

Rationale: This NASA Procedural Requirements (NPR) provides the basis for the NASA Safety Program and serves as a general framework to structure more specific and detailed requirements for NASA Headquarters, Programs, and Centers.

The listed sections provide specific safety standards for hardware that could impact the HLS design. Not all section listed in HEOMD-003 were listed. The programmatic requirements were removed and are being captured in the HLS Safety and Mission Assurance Plan or in contractual requirements.

HLS-SMA-0019 Software Safety Standards

The HLS shall meet the intent of NASA-STD-8719.13C, Software Safety Standard, Chapters 4-7 and Appendix A for safety criticality flight and ground software.

Rationale: This Standard describes the activities required to ensure and promote safety processes that are utilized for software that is created, acquired, or maintained by or for NASA.

HLS-SMA-0020 Workmanship Standard for Polymeric Application on Electronic Assemblies

The HLS shall meet the intent of NASA-STD-8739.1B, Workmanship Standard for Polymeric Application on Electronic Assemblies, for all electronic assemblies on board the HLS.

Rationale: This standard prescribes NASA's technical and quality assurance requirements for polymeric applications for electrical and electronic assemblies and sets forth requirements for staking, conformal coating, bonding, and encapsulation of components used in electronic hardware.

HLS-SMA-0021 Workmanship Standard for Crimping, Interconnecting Cables, Harnesses, and Wiring

The HLS shall meet the intent of NASA-STD-8739.4A, Workmanship Standard for Crimping, Interconnecting Cables, Harnesses, and Wiring, for all crimping, interconnecting cables, wiring, and harnesses on board the HLS.

Rationale: The purpose of this NASA Technical Standard is to set forth requirements for interconnecting cable and harness assemblies that connect electrical, electronic or electromechanical components.

This standard applies to critical work. Where Critical work is defined as any task that if performed incorrectly or in violation of prescribed requirements poses a credible risk of loss of human life; serious injury; loss of a Class A, B, or C payload (see NPR 8705.4); loss of a Category 1 or Category 2 mission (see NPR 7120.5); or loss of a mission resource valued at greater than $2M (e.g., NASA space flight hardware, Government test or launch facility).

HLS-SMA-0022 Workmanship Standard for Fiber Optic Terminations, Cable Assemblies, and Installation

The HLS shall meet the intent of NASA-STD 8739.5A, Workmanship Standard for Fiber Optic Terminations, Cable Assemblies, and Installation, for all fiber Optic cables on board the HLS.

Rationale: This Standard sets forth termination and cabling requirements for optical fiber and cable assemblies.

This standard applies to critical work. Where Critical work is defined as any task that if performed incorrectly or in violation of prescribed requirements poses a credible risk of loss of human life; serious injury; loss of a Class A, B, or C payload (see NPR 8705.4); loss of a Category 1 or Category 2 mission (see NPR 7120.5); or loss of a mission resource valued at greater than $2M (e.g., NASA space flight hardware, Government test or launch facility).

HLS-SMA-0023 Implementation Requirements for NASA Workmanship Standards

The HLS shall meet the intent of NASA-STD-8739.6A, Implementation Requirements for NASA Workmanship Standards for on board the HLS.

Rationale: The purpose of this standard is to provide quality requirements for the manufacture of electronic assemblies and for electrostatic discharge (ESD) control.

This standard applies to critical work. Where Critical work is defined as any task that if performed incorrectly or in violation of prescribed requirements poses a credible risk of loss of human life; serious injury; loss of a Class A, B, or C payload (see NPR 8705.4); loss of a Category 1 or Category 2 mission (see NPR 7120.5); or loss of a

mission resource valued at greater than $2M (e.g., NASA space flight hardware, Government test or launch facility).

HLS-SMA-0026 Electrical, Electronic, and Electromagnetic (EEE) Parts Assurance

The HLS shall meet the intent of NASA-STD-8739.10, Electrical, Electronic, And Electromagnetic (EEE) Parts Assurance Standard, for all EEE parts on board the HLS.

Rationale: The purpose of this standard is to establish a consistent set of requirements to control risk and enhance reliability in NASA space flight hardware and critical ground support equipment, in part, by managing the selection, acquisition, traceability, testing, handling, packaging, storage, and application of EEE parts as required by NASA Policy Directive (NPD) 8730.2, NASA Parts Policy.

While this document may give guidance with respect to processes and selection criteria associated with EEE parts, it is generally not the intent of this standard to mandate specific reliability grade parts in particular applications, rather to allow programs and projects to make these decisions based on the guidance contained herein.

D.2 Environmental Conditions

D.2.1 Natural Environments

HLS-DCE-0001 Natural Environments

The HLS shall meet all safety, performance, utilization, and mission objectives during and after exposure to natural environments as defined in SLS-SPEC-159 Cross-Program DSNE and NASA/TM-2016-218229 NEDD. Applicability of each environment by mission phase is defined in 3.2.1-1 Table NE1.

Rationale: HLS hardware must perform in all of the natural space environments including ionizing radiation, meteoroids, orbital debris (during earth orbit and departure phase), plasma/spacecraft charging, natural thermal, gravitational, etc., environments.

Table NE1. Applicability matrix for natural space environments definition for Human Landing System

The following table provides pointers to the appropriate sections of DSNE and NEDD to use in understanding the environments for HLS.

	Mission Phase					
	DSNE paragraph				NEDD paragraph (unless noted)	
Environment	Earth launch/ascent	Low earth orbit loiter	Post-TLI (rad. belt)	Cruise and cis-lunar	Lunar Surface	Notes
Ionizing Rad. Dose	n/a	3.3.1.1	3.3.1.2.2	3.3.1.10.2	9.7.1 + DSNE 3.3.1.10.2	divide DSNE by 2 for shielding by the Moon
Ionizing Rad. SEE	3.2.13	3.3.2.1	3.3.2.2.2	3.3.2.10.2	9.7.1 + DSNE 3.3.2.10.2	divide DSNE by 2 for shielding by the Moon
Plasma/charging	n/a	3.3.3.1	3.3.3.2.2 and 3.3.3.3	3.3.3.4 and 3.3.3.5	9.3.4.4	surface interaction effects not included
Meteoroid/Orb. Debris	n/a	3.3.6	3.3.6	3.3.6 meteoroids only	DSNE 3.3.6 meteoroids only	use MEM 3 which was recently released
Meteoroid ejecta	n/a	n/a	n/a	n/a	9.8.6	update is underway
Earth Gravity Field	3.3.7	3.3.7	3.3.7	3.3.7	n/a	
Lunar Gravity Field	n/a	n/a	n/a	3.3.8	DSNE 3.3.8	
Thermal env.	3.3.9.2	3.3.9.2	3.3.9.2	3.3.9.1	9.6	
Solar illumination	3.3.10	3.3.10	3.3.10	3.3.10	9.4.1 + DSNE 3.3.10	
Neutral atmosphere	3.3.11	3.3.11	n/a	n/a	n/a	
Regolith properties	n/a	n/a	n/a	n/a	9.3	
Dust	n/a	n/a	n/a	n/a	9.5	
Regolith electrical prop.	n/a	n/a	n/a	n/a	9.3.4	
Regolith optical prop.	n/a	n/a	n/a	n/a	none available, in development	
Surface feature prop.	n/a	n/a	n/a	n/a	9.2	

D.3 Engineering Design and Construction Standards

This section applies design and construction standards to the HLS. The overall purpose of the engineering design and construction standards is to levy best practices that will help ensure a quality HLS end item is realized. The design and construction standards can generally be categorized to two groups: direct and indirect design and construction standards. Direct design and construction standards provide guidance that directly influence the end item design. Indirect design and construction standards provide guidance on data products and activities that should be produced or completed that will provide insight into the quality of the end item, but they do not directly influence the design.

HLS-DCS-0001 Electromagnetic Effects

The HLS shall be developed in accordance with MIL-STD-464, Electromagnetic Environmental Effects Requirements for Systems.

Rationale: MIL-STD-464, 1.1 Purpose, states "This standard establishes electromagnetic environmental effects (E3) interface requirements and verification criteria for … space… systems, including associated ordnance." MIL-STD-464 is considered an indirect standard. The verification approach for this standard is by insight.

Note: DSG-RQMT-004, Gateway Electromagnetic Environmental Effects (E3) Requirements Document, Section 3.7.2, is a potential starting point for tailoring of this standard.

HLS-DCS-0002 Structural Design Requirements

The system shall accommodate the physical characteristics and capabilities as provided by NASA in Physical Characteristics and Capabilities Data Set.
Rationale: JSC 65828, 1.1 Purpose, states "This document establishes the structural requirements for human-rated spaceflight hardware including … spacecraft". JSC 65828 is considered an indirect standard. The verification approach for this standard is at the standard level through a compliance summary statement.

Note: DSG-RQMT-005, Gateway Structural Design Requirements and Factors of Safety for Spaceflight Hardware, is a potential starting point for tailoring of this standard.

HLS-DCS-0003 Loads and Structural Dynamics

The HLS shall be developed in accordance with JSC 65829, Loads and Structural Dynamics Requirements for Spaceflight Hardware

Rationale: JSC 65829, 1.1 Purpose, states 'This document establishes the structural requirements for human-rated spaceflight hardware including launch vehicles, spacecraft and payloads." JSC 65829 is considered an indirect standard. The verification approach for this standard is at the individual applicable requirements contained within the standard.

Note DSG-RQMT-006, Gateway Loads and Structural Dynamics Requirements for Spaceflight Hardware, is a potential starting point for tailoring of this standard.

HLS-DCS-0004 Control of Electromagnetic Interference Characteristics

The HLS shall be developed in accordance with HLS-STD-007, Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment.

Rationale: HLS-STD-007, 1.1 Purpose, states "This standard establishes interface and associated verification requirements for the control of the electromagnetic interference (EMI) emission and susceptibility characteristics of electronic, electrical, and electromechanical equipment and subsystems…" HLS-STD-007 is considered an indirect standard. The verification approach for this standard is by insight.

Note: HLS-STD-007 was derived from MIL-STD-461 and incorporates tailoring that ensures that HLS will remain compatible with Deep Space Gateway.

HLS-DCS-0005 Mechanisms

The HLS shall be developed in accordance with NASA-STD-5017, Design and Development Requirements for Mechanisms.

Rationale: NASA-STD-5017, 1.1 Purpose, states "The purpose of this NASA Technical Standard is to establish common National Aeronautics and Space Administration (NASA) design, development, and test requirements for mechanisms whose operation is required for safety or mission success." NASA-STD-5017 is considered an indirect standard. The verification approach for this standard is at the individual applicable requirements contained within the standard.

Note: DSG-RQMT-008, Gateway Design and Development Requirements for Mechanisms, is a potential starting point for tailoring of this standard

HLS-DCS-0006 Fasteners

The HLS shall be designed in accordance with NASA-STD-5020 Requirements for Threaded Fastening Systems in Spaceflight Hardware.

Rationale: The intent of NASA-STD-5020 is to ensure the integrity of threaded fastening systems and to prevent the possibility of joint separation.

Note: DSG-RQMT-009, Gateway Requirements for Threaded Fastening Systems in Spaceflight Hardware, is a potential starting point for tailoring of this standard. NASA-STD-5020 is considered a direct standard. The verification approach for this standard is by insight.

HLS-DCS-0007 Models and Simulations

The HLS shall be developed in accordance with NASA-STD-7009, Standards for Models and Simulations.

Rationale: .NASA-STD-7009, 1.1 Purpose, state "The primary purpose of this NASA Technical Standard is to reduce the risks associated with M&S-influenced decisions by ensuring the complete communication of the credibility of M&S results." NASA-STD-7009 is considered an indirect standard. The verification approach for this standard is at the standard level through a compliance summary statement.

Note: DSG-PLAN-016, Gateway Program Modeling and Simulation Plan, is a potential starting point for tailoring of this standard.

HLS-DCS-0008 Fracture Control

The HLS shall be developed in accordance with NASA-STD-5019, Fracture Control Requirements for Spaceflight Hardware, for hardware structures of the integrated vehicle.

Rationale: NASA-STD-5019, 1.1 Purpose, states "The purpose of this NASA Technical Standard is to establish the fracture control requirements for National Aeronautics and Space Administration (NASA) human-rated spaceflight hardware. In accordance with NASA Procedural Requirements (NPR) 8705.2B, Human-Rating Requirements for Space Systems, it is NASA's policy to produce human-rated space systems that have failure tolerance for catastrophic events or that potentially catastrophic hazards are controlled through a defined process in which approved standards and margins are implemented that account for the absence of failure tolerance." NASA-STD-5019 is considered an indirect standard. The verification approach for this standard is at the standard level through a compliance summary statement.

Note: DSG-RQMT-019, Gateway Fracture Control Requirements for Spaceflight Hardware, is a potential starting point for tailoring of this standard.

HLS-DCS-0009 Thin Walled Flexible Pressure Boundary

The HLS shall be developed in accordance with JSC 67035, Best Practices and Guidelines (BP&G) for Thin Wall Pressure Boundaries (TWPB) for Human Spaceflight Applications

Rationale: JSC 67035, 1.1 Purpose, states "The purpose of this document is to define the requirements and verifications applicable to fracture critical, metallic, thin-walled flexible pressure boundary (TWFPB) hardware items used in propulsion and fluid systems on human spacecraft elements". JSC 67035 is considered an indirect standard. The verification approach for this standard is at the standard level through a compliance summary statement.

HLS-DCS-0010 Strength and Life Requirements for Propulsion Systems

The HLS shall be developed in accordance with NASA-STD-5012, Strength and Life Assessment Requirements for Liquid Fueled Space Propulsion Systems Engines.

Rationale: NASA-STD-5012, Section 1.1 Purpose, states "purpose of this NASA Technical Standard is to provide a consistent set of requirements to be used in designing and assessing liquid – fuel propulsion system engines." NASA-STD-5012 is considered an indirect standard. The verification approach for this standard is at the standard level through a compliance summary statement.

HLS-DCS-0011 Windows

The HLS shall be designed in accordance with NASA-STD-5018 Strength Design and Verification Criteria for Glass, Ceramics, and Windows in Human Space Flight Applications.

Rationale: NASA-STD-5018 §1.2 Applicability states that the intent of the standard is, "to ensure the structural integrity and reliability of human-rated spacecraft." NASA-STD-5018 §1.3 then states, "WARNING: Significant inherent risks exist with the use of brittle materials, such as glass and ceramics, in spacecraft". The standard then states, "These requirements guide window and glass/ceramic designs that ensure the safety of flight." NASA-STD-5018 is considered a direct standard. The verification approach for this standard is by insight.

HLS-DCS-0012 Metallic Pressure Vessels

The HLS shall be designed in accordance with AIAA-S-080-2018 Standard: Space Systems - Metallic Pressure Vessels, Pressurized Structures, and Pressure Components.

Rationale: The AIAA-S-080-2018 section on Purpose states that the intent of the standard is to, "…assure a high level of confidence in achieving safe and reliable operation." The AIAA-S-080-2018 section on Application states, "This standard is applicable to space flight metallic pressurized hardware. Included are all pressure vessels, pressurized structures, batteries, heat pipes, cryostats, sealed containers, and pressure components such as lines, fittings, and hoses made of metals." AIAA-S-080-2018 is considered a direct standard. The verification approach for this standard is at the individual applicable requirements contained within the standard.

HLS-DCS-0013 Composite Overwrapped Pressure Vessels

The HLS shall be designed in accordance with AIAA-S-081B-2018 Standard: Space Systems – Composite Overwrapped Pressure Vessels.

Rationale: The AIAA-S-081-2018 section on Purpose states that the intent of the standard as, "These requirements are intended to assure the safety and enhance the success of the operation of a COPV in an aerospace system." The AIAA-S-081-2018 section on Applicability states, "This standard is applicable only to COPVs containing a metallic liner and constructed with a carbon fiber/ polymer matrix overwrap. COPVs that include a fiberglass overwrap layer that serves only to protect the vessel from impact damage are permitted." AIAA-S-081-2018 is considered a direct standard. The verification approach for this standard is at the individual applicable requirements contained within the standard.

HLS-DCS-0014 Materials and Processes

The HLS shall be developed in accordance with NASA-STD-6016, Standard Materials and Processes Requirements for Spacecraft. Deviations from materials and processes requirements shall be documented and approved using the intent of the Materials Usage Agreement (MUA) as defined in NASA-STD-6016

Rationale: NASA-STD-6016, 1.1 Purpose, states "The purpose of this NASA Technical Standard is to define the minimum requirements for M&P and to provide a general control specification for incorporation in NASA program/project hardware procurements and technical programs." NASA-STD-6016 is considered an indirect standard. The verification approach for this standard is at the standard level through a compliance summary statement.

HLS-DCS-0015 Software Engineering

The HLS shall be developed in accordance with NPR 7150.2B, NASA Software Engineering Requirements, for all flight and ground software products classified as Class A software per Appendix E of NPR 7150.2B, or safety critical as defined in NASA-STD-8719.13, Appendix A, that adversely affects the operation of the Class A products. A requirements mapping matrix is provided for each software class and criticality in Appendix D of NPR 7150.2B.

Rationale: NPR 7150.2B, P.1 Purpose, states "This directive establishes the engineering requirements for software acquisition, development, maintenance, retirement, operations, and management". NPR 7150.2B is considered an indirect standard. The verification approach for this standard is at the standard level through a compliance summary statement.

HLS-DCS-0016 Electrostatic Discharge Control Program

The HLS shall be developed in accordance with ANSI/ESD S20.20, For the Development of an Electrostatic Discharge Control Program for - Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices), which will include establishing and maintaining an electrostatic discharge control plan.

Rationale: ANSI/ESD S20.20, 1.0 Purpose, states "The purpose of this standard is to provide administrative and technical requirements for establishing, implementing and maintaining an ESD Control Program". ANSI/ESD S20.20 is considered an indirect standard. The verification approach for this standard is by insight.

HLS-DCS-0017 Test Requirements

The HLS shall be developed in accordance with SMC-S-016, Test Requirements for Launch, Upper-Stage, and Space Vehicles.

Rationale: SMC-S-016, 1.1 Purpose, states "This standard establishes the environmental testing requirements for… space vehicles, and their subsystems and units." SMC-S-016 is considered an indirect standard. The verification approach for this standard is at the individual applicable requirements contained within the standard.

HLS-DCS-0018 Pyrotechnics

The HLS shall be designed in accordance with JSC 62809, Human Rated Spacecraft Pyrotechnic Specification.

Rationale: JSC 62809, 1.0 Scope, states "This specification… covers requirements for all phases of pyrotechnics use, including design, development, qualification, production, acceptance, shipping, storage, handling, installation, and checkout for [human] spacecraft". JSC 62809 is considered a direct standard. The verification approach for this standard is at the standard level through a compliance summary statement.

HLS-DCS-0019 Batteries

The HLS shall designed in accordance with JSC 20793, Crewed Space Vehicle Battery Safety Requirements.

Rationale: JSC 20793, 1.1 Purpose and Scope, states "[This standard] defines the specific provisions required to design a battery that is safe for ground personnel and crew members to handle and/or operate during all applicable phases of crewed missions, safe for use in the enclosed environment of a crewed space vehicle, and safe for use in launch vehicles, as well as in unpressurized spaces adjacent to the habitable portion of a space vehicle. The required provisions encompass hazard controls, design evaluation, and verification." JSC 20793 is considered a direct standard. The verification approach for this standard is at the standard level through a compliance summary statement.

HLS-DCS-0020 Solar Cells

The HLS shall be developed in accordance with AIAA S-111-2005, Qualification and Quality Requirements for Space Solar Cells.

Rationale: AIAA S-111-2005, 1 Scope, states "This document establishes qualification and quality requirements for … solar cell types for space applications. This includes requirements for solar cell manufacturer quality systems and for characterization of solar cells." AIAA S-111-2005 is considered an indirect standard. The verification approach for this standard is by insight.

HLS-DCS-0021 Solar Panels

The HLS shall be developed in accordance with AIAA S-112-2005, Qualification and Quality Requirements for Space Solar Panels.

Rationale: AIAA S-112-2005, 1 Scope, states "This document establishes qualification and quality requirements for the electrical components integrated onto spacecraft solar." AIAA S-112-2005 is considered an indirect standard. The verification approach for this standard is by insight.

HLS-DCS-0022 EEE Parts

The HLS shall be designed in accordance with the Air Force Space Command's standard SMC-S-010 Parts, Materials, and Processes: Technical Requirements for Space and Launch Vehicles. The following sections of SMC-S-010 are NOT applicable:

1. Paragraphs 4.1.2, 4.3.1.2, 4.3.2
2. Paragraphs 4.5 and 4.7 including their sub paragraphs
3. Sections 100, 110, 120 and 1700 through 3500 inclusive.
4. Appendix D

All other parts of the document are applicable.

Rationale: The SMC-S-010 §1.1 Purpose states, "This document establishes the minimum technical requirements for electronic parts, materials, and processes (electronic PMP) used in the design, development, and fabrication of space vehicles." SMC-S-010 is considered a direct standard. The verification approach for this standard is at the standard level through a compliance summary statement.

Note: EEE-INST-002 Instructions for EEE Parts Selection, Screening, Qualification, and Derating is a potential starting point for tailoring of this standard.

HLS-DCS-0024 Printed Boards

The HLS shall be designed in accordance with IPC-2221, Generic Standard on Printed Board Design, as well as the associated technology performance specification under the IPC-2220 series per Performance Class 3. IPC-2220 applicable documents are:
2221B
2222A
2223D
2224BL
2225BL
2226BL

Rationale: IPC-2221, 1.1. Purpose, states "The requirements contained herein are intended to establish design principles and recommendations that shall be used …to produce detailed designs intended to mount and connect components." IPC-2220 series is considered a direct standard. The verification approach for this standard is by insight.

HLS-DCS-0025 Qualification of Printed Boards Standard

The HLS shall be developed in accordance with IPC-6011, Generic Performance Specification for Printed Boards, as well as the associated technology performance specifications of the IPC-6010 series per Performance Class 3, Class 3/A and the Space Addendums. IPC-6010 applicable documents are:

6011
6012DS
6013C
6015
6017
6018CS

Rationale: IPC-6011, 1.1 Statement of Scope, states "This specification establishes the general requirements for printed boards and the quality and reliability assurance requirements that must be met for their acquisition. The intent of this specification is to allow the Printed Board user and supplier flexibility to develop optimum procedures for the Manufacture and Procurement of Printed Boards." IPC-6011 is considered an indirect standard. The verification approach for this standard is by insight.

HLS-DCS-0027 Soldering Process and Controls Standard

The HLS shall be developed in accordance with IPC J-STD-001F, Requirements for Soldered Electrical and Electronic Assemblies,including IPC J-STD-001FS Amendment 1.

Rationale: IPC-J-STD-001F, 1.2 Purpose, states "This standard describes materials, methods and acceptance criteria for producing soldered electrical and electronic assemblies. The intent of this document is to rely on process control methodology to ensure consistent quality levels during the manufacture of products." IPC J-STD-001F is considered an indirect standard. The verification approach for this standard is by insight.

HLS-DCS-0029 Custom Electromagnetic Devices

The HLS shall be developed in accordance with MIL-STD-981, Design, Manufacturing and Quality Standards for Custom Electromagnetic Devices for Space Applications.

Rationale: MIL-STD-981, 1.1 Scope, states "This standard establishes the requirements for acceptable design, manufacturing, and quality control criteria for custom electromagnetic, open and closed construction, leaded and surface mount devices for space applications." MIL-STD-981 is considered an indirect standard. The verification approach for this standard is by insight.

HLS-DCS-0030 Electrical Bonding

The HLS shall be designed in accordance with NASA-STD-4003 Electrical Bonding for NASA Launch Vehicles, Spacecraft, Payloads, and Flight Equipment.

Rationale: NASA-STD-4003, section 1.1 Purpose, states that, "[This standard's] intent is to provide fundamental aerospace electrical bonding requirements [to protect

personnel and equipment from shock]. NASA-STD-4003 is considered a direct standard. The verification approach for this standard is by insight.

HLS-DCS-0031 Flexible Lines for Flow Induced Vibrations

The HLS shall be designed in accordance with MSFC-DWG-20M02540, Assessment of Flexible Lines for Flow Induced Vibrations.

Rationale: MSFC-DWG-20M02540, 1.1 Scope, states “The purpose of this document is to establish the analytical methods for determining wether a given design of an annular convoluted metal bellows or flexhose is susceptible to flow-induced vibrations.” MSFC-DWG-20M02540 is considered a direct standard. The verification approach for this standard is at the standard level through a compliance summary statement.

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Appendix E Requirements Cross Matrix

Original Requirement ID	SRD Requirement ID	Requirement Title
N/A	HLS-DCE-0001	Natural Environments
N/A	HLS-DCI-0001	Avionics Interoperability
N/A	HLS-DCI-0002	Communication Interoperability
N/A	HLS-DCI-0003	ECLSS Interoperability
N/A	HLS-DCI-0004	Power System Interoperability
N/A	HLS-DCI-0005	Rendezvous System Interoperability
N/A	HLS-DCI-0006	Robotic Interoperability
N/A	HLS-DCI-0007	Thermal System Interoperability
N/A	HLS-DCS-0001	Electromagnetic Effects
N/A	HLS-DCS-0002	Structural Design Requirements
N/A	HLS-DCS-0003	Loads and Structural Dynamics
N/A	HLS-DCS-0004	Control of Electromagnetic Interference Characteristics
N/A	HLS-DCS-0005	Mechanisms
N/A	HLS-DCS-0006	Fasteners
N/A	HLS-DCS-0007	Models and Simulations

Original Requirement ID	**SRD Requirement ID**	**Requirement Title**
N/A	HLS-DCS-0008	Fracture Control
N/A	HLS-DCS-0009	Thin Walled Flexible Pressure Boundary
N/A	HLS-DCS-0010	Strength and Life Requirements for Propulsion Systems
N/A	HLS-DCS-0011	Windows
N/A	HLS-DCS-0012	Metallic Pressure Vessels
N/A	HLS-DCS-0013	Composite Overwrapped Pressure Vessels
N/A	HLS-DCS-0014	Materials and Processes
N/A	HLS-DCS-0015	Software Engineering
N/A	HLS-DCS-0016	Electrostatic Discharge Control Program
N/A	HLS-DCS-0017	Test Requirements
N/A	HLS-DCS-0018	Pyrotechnics
N/A	HLS-DCS-0019	Batteries
N/A	HLS-DCS-0020	Solar Cells
N/A	HLS-DCS-0021	Solar Panels
N/A	HLS-DCS-0022	EEE Parts
N/A	HLS-DCS-0023	Electrostatic Design Thresholds
N/A	HLS-DCS-0024	Printed Boards

Original Requirement ID	**SRD Requirement ID**	**Requirement Title**
N/A	HLS-DCS-0025	Qualification of Printed Boards Standard
N/A	HLS-DCS-0026	Component Mounting Guidelines
N/A	HLS-DCS-0027	Soldering Process and Controls Standard
N/A	HLS-DCS-0028	Soldering Requirements
N/A	HLS-DCS-0029	Custom Electromagnetic Devices
N/A	HLS-DCS-0030	Electrical Bonding
HMTA-3006	HLS-HMTA-0001	Design Using Human-Centered Task Analysis
HMTA-4000	HLS-HMTA-0002	Accommodate Physical Characteristics of Crew
HMTA-4013	HLS-HMTA-0003	Muscle Effects
HMTA-4015	HLS-HMTA-0004	Aerobic Capacity
HMTA-5000	HLS-HMTA-0005	Perception and cognition capabilities
HMTA-5001	HLS-HMTA-0006	Visual Capabilities
HMTA-5002	HLS-HMTA-0007	Auditory Perceptual Capabilities
HMTA-5003	HLS-HMTA-0008	Sensorimotor Capabilities
HMTA-5004	HLS-HMTA-0009	Cognitive Capabilities
HMTA-5005	HLS-HMTA-0010	Time and Performance
HMTA-5006	HLS-HMTA-0011	Situational Awareness (SA)

Original Requirement ID	**SRD Requirement ID**	**Requirement Title**
HMTA-5007	HLS-HMTA-0012	Nominal Cognitive Workload
HMTA-5008	HLS-HMTA-0013	Off-Nominal Cognitive Workload
HMTA-6000	HLS-HMTA-0014	Shirt Sleeve Environment
HMTA-6001	HLS-HMTA-0015	Trend Analysis of Environmental Data
HMTA-6002	HLS-HMTA-0016	Inert Diluent Gas
HMTA-6003	HLS-HMTA-0017	O2 Partial Pressure Range for Crew Exposure
HMTA-6004	HLS-HMTA-0018	Nominal Vehicle/Habitat Carbon Dioxide Levels
HMTA-6005	HLS-HMTA-0019	Ventilation Rate
HMTA-6006	HLS-HMTA-0020	Total Pressure Tolerance Range for Indefinite Crew Exposure
HMTA-6007	HLS-HMTA-0021	Rate of Pressure Change
HMTA-6010	HLS-HMTA-0022	Relative Humidity
HMTA-6012	HLS-HMTA-0023	Comfort Zone
HMTA-6013	HLS-HMTA-0024	Temperature Comfort Range
HMTA-6017	HLS-HMTA-0025	Atmospheric Control
HMTA-6020	HLS-HMTA-0026	Atmospheric Data Recording
HMTA-6021	HLS-HMTA-0027	Atmospheric Data Displaying
HMTA-6022	HLS-HMTA-0028	Atmospheric Monitoring and Alerting

Original Requirement ID	**SRD Requirement ID**	**Requirement Title**
HMTA-6023	HLS-HMTA-0414	Trace Constituent Monitoring and Alerting
HMTA-6024	HLS-HMTA-0029	Combustion Monitoring and Alerting
HMTA-6025	HLS-HMTA-0030	Contamination Monitoring and Alerting
HMTA-6008	HLS-HMTA-0031	Decompression Sickness (DCS) Risk Mitigation
HMTA-6009	HLS-HMTA-0032	Decompression Sickness Treatment Capability
HMTA-6026a	HLS-HMTA-0033	Potable Water
HMTA-6026	HLS-HMTA-0034	Potable Water Physiochemical Limits
HMTA-6027	HLS-HMTA-0035	Potable Water Microbial Limits
HMTA-6105	HLS-HMTA-0040	Water Treatment Chemicals and Residual Biocides
HMTA-6029	HLS-HMTA-0036	Drinking Water Quantity
HMTA-6040	HLS-HMTA-0037	Water Dispensing Increments
HMTA-6039	HLS-HMTA-0038	Water Dispensing Rate
HMTA-6041	HLS-HMTA-0040	Water Temperature
HMTA-6047	HLS-HMTA-0041	Toxic Hazard Level Three
HMTA-6048	HLS-HMTA-0042	Toxic Hazard Level Four
HMTA-6049	HLS-HMTA-0043	Chemical Decomposition
HMTA-6050	HLS-HMTA-0044	Atmosphere Contamination Limit – Airborne Contaminants

Original Requirement ID	**SRD Requirement ID**	**Requirement Title**
HMTA-6052	HLS-HMTA-0046	Particulate Matter
HMTA-6053	HLS-HMTA-0047	Lunar Dust Contamination
HMTA-6056a	HLS-HMTA-0048	Design for Cleanliness
HMTA-6056	HLS-HMTA-0049	Surface Cleanability
HMTA-6058	HLS-HMTA-0050	Condensation Limitation
HMTA-6059	HLS-HMTA-0051	Microbial Air Contamination Prevention
HMTA-6061	HLS-HMTA-0052	Cross-Contamination
HMTA-6062	HLS-HMTA-0053	Availability of Environmental Hazards Information
HMTA-6063	HLS-HMTA-0054	Contamination Cleanup
HMTA-7079	HLS-HMTA-0055	Accessibility for Cleaning
HMTA-7080	HLS-HMTA-0056	Particulate Control
HMTA-7083	HLS-HMTA-0057	Cleaning Materials
HMTA-7019	HLS-HMTA-0058	Hygiene Equipment Cleanliness
HMTA-6064	HLS-HMTA-0059	Sustained Translational Acceleration Limits
HMTA-6065	HLS-HMTA-0060	Rotational Velocity
HMTA-6066	HLS-HMTA-0061	Sustained Rotational Acceleration Due to Cross-Coupled Rotation
HMTA-6067	HLS-HMTA-0415	Transient Rotational Acceleration

Original Requirement ID	**SRD Requirement ID**	**Requirement Title**
HMTA-6069	HLS-HMTA-0062	Transient Translational Acceleration
HMTA-6068	HLS-HMTA-0063	Acceleration Rate of Change
HMTA-6107	HLS-HMTA-0065	Vehicle Acceleration Monitoring and Analysis
HMTA-6109	HLS-HMTA-0066	Hang Time Limit
HMTA-6073a	HLS-HMTA-0067	Acoustic Limits
HMTA-6080	HLS-HMTA-0068	Intermittent Noise Limits
HMTA-6080A	HLS-HMTA-0069	Cabin Depressurization Valve Hazardous Noise Limit - Initial
HMTA-6080b	HLS-HMTA-0070	Cabin Depressurization Valve Noise Dose Limits
HMTA-6073	HLS-HMTA-0071	Ascent, Landing and Abort Noise Exposure Limits
HMTA-6074	HLS-HMTA-0072	Sound Ceiling Limit for Ascent and Landing
HMTA-6075	HLS-HMTA-0073	Ceiling Limit for Aborts
HMTA-6076	HLS-HMTA-0074	Ascent, Landing, Abort and other burn Impulse Noise Limits
HMTA-6077	HLS-HMTA-0075	Hazardous Noise Limits for All Phases Except Ascent, Landing, Aborts and other lander burns
HMTA-6078	HLS-HMTA-0076	Continuous Noise Limits
HMTA-6081	HLS-HMTA-0077	Alarm Maximum Sound Level Limit
HMTA-6082	HLS-HMTA-0078	Annoyance Noise Limits for Crew Sleep
HMTA-6083	HLS-HMTA-0079	Impulse Noise Limit

Original Requirement ID	**SRD Requirement ID**	**Requirement Title**
HMTA-6084	HLS-HMTA-0080	Narrow-Band Noise Limits
HMTA-6085	HLS-HMTA-0081	Infrasonic Sound Pressure Limits
HMTA-6106	HLS-HMTA-0082	Noise Limit for Personal Communication Devices
HMTA-6089a	HLS-HMTA-0083	Vibration Limits
HMTA-6090	HLS-HMTA-0084	Vibration Exposures During Dynamic Phases of Flight
HMTA-6091	HLS-HMTA-0085	Long-Duration Vibration Exposure Limits for Health during Non-Sleep Phases of Mission
HMTA-6092	HLS-HMTA-0086	Vibration Exposure Limits during Sleep
HMTA-6093	HLS-HMTA-0087	Vibration Limits for Performance
HMTA-6095a	HLS-HMTA-0088	Radiation protection, limitations and monitoring
HMTA-6097	HLS-HMTA-0089	Crew Radiation Exposure Limits
HMTA-6100	HLS-HMTA-0090	Ionizing Radiation Alerting
HMTA-6110	HLS-HMTA-0091	Natural Sunlight Exposure Limits
HMTA-6111	HLS-HMTA-0092	Artificial Light Exposure Limits for Visible sources below 10,000 nits
HMTA-6112	HLS-HMTA-0093	Artificial Light Exposure Limits for Visible sources above 10,000 nits and Infrared (IR) Sources
HMTA-6113	HLS-HMTA-0094	Artificial Light Exposure Limits for Ultraviolet (UV) Sources
HMTA-6114	HLS-HMTA-0095	RF Non-Ionizing Radiation Exposure Limits
HMTA-6115	HLS-HMTA-0096	Laser Exposure Limits

Original Requirement ID	SRD Requirement ID	Requirement Title
HMTA-6116	HLS-HMTA-0097	Solar Particle Event (SPE) protection
HMTA-7000	HLS-HMTA-0098	Nutrition Care (GFE)
HMTA-7008	HLS-HMTA-0099	Food Preparation
HMTA-7009	HLS-HMTA-0100	Food Preparation and Cleanup
HMTA-7010	HLS-HMTA-0101	Food Contamination Control
HMTA-7011	HLS-HMTA-0102	Food and Beverage Heating
HMTA-7014	HLS-HMTA-0103	Food Spill Control
HMTA-7015	HLS-HMTA-0104	Food System Cleaning and Sanitizing
HMTA-7016	HLS-HMTA-0105	Personal Hygiene Capability
HMTA-7200	HLS-HMTA-0106	Crew Task Volume
HMTA-7012	HLS-HMTA-0107	Dining Accommodations
HMTA-7017	HLS-HMTA-0108	Body Cleansing Privacy
HMTA-7018	HLS-HMTA-0109	Personal Hygiene Provision
HMTA-7020	HLS-HMTA-0111	Body Waste Management Capability
HMTA-7021	HLS-HMTA-0112	Body Waste Management System Location
HMTA-7022	HLS-HMTA-0113	Body Waste Management Privacy
HMTA-7023	HLS-HMTA-0114	Body Waste Management Provision

Original Requirement ID	SRD Requirement ID	Requirement Title
HMTA-7026	HLS-HMTA-0115	Body Waste Odor
HMTA-7027	HLS-HMTA-0116	Body Waste Trash Receptacle Accessibility
HMTA-7028	HLS-HMTA-0117	Private Body Inspection Accommodation
HMTA-7029	HLS-HMTA-0118	Body Waste Management System Cleanliness
HMTA-7043	HLS-HMTA-0119	Medical Capability - GFE
HMTA-7047	HLS-HMTA-0120	Biological Waste Containment and Disposal
HMTA-7046	HLS-HMTA-0121	Medical Treatment Restraints
HMTA-7048	HLS-HMTA-0122	Medical Sharps Disposal
HMTA-7049	HLS-HMTA-0123	Deceased Crew
HMTA-7050	HLS-HMTA-0124	Stowage Provisions
HMTA-7051	HLS-HMTA-0125	Personal Stowage
HMTA-7052	HLS-HMTA-0126	Stowage Location
HMTA-7053	HLS-HMTA-0127	Stowage Interference
HMTA-7054	HLS-HMTA-0128	Stowage Restraints
HMTA-7055	HLS-HMTA-0129	Priority of Stowage Accessibility
HMTA-7056	HLS-HMTA-0130	Stowage Operation without Tools
HMTA-7057	HLS-HMTA-0131	Stowage Access while Suited

Original Requirement ID	**SRD Requirement ID**	**Requirement Title**
HMTA-7059	HLS-HMTA-0132	Inventory Tracking
HMTA-7058	HLS-HMTA-0133	Identification System
HMTA-7060	HLS-HMTA-0134	Inventory Operations
HMTA-7061	HLS-HMTA-0135	Nomenclature Consistency
HMTA-7062	HLS-HMTA-0136	Unique Item Identification
HMTA-7063	HLS-HMTA-0137	Interchangeable Item Nomenclature
HMTA-7064	HLS-HMTA-0138	Trash Accommodation
HMTA-7065	HLS-HMTA-0139	Trash Volume Allocation
HMTA-7066	HLS-HMTA-0140	Trash Stowage Interference
HMTA-7067	HLS-HMTA-0141	Trash Odor Control
HMTA-7068	HLS-HMTA-0142	Trash Contamination Control
HMTA-7013	HLS-HMTA-0143	Food System Waste
HMTA-7070a	HLS-HMTA-0144	Sleep
HMTA-7070	HLS-HMTA-0145	Sleep Accommodation
HMTA-7073	HLS-HMTA-0146	Partial-g Sleeping
HMTA-8000	HLS-HMTA-0148	Architecture
HMTA-8001	HLS-HMTA-0149	Volume Allocation

Original Requirement ID	**SRD Requirement ID**	**Requirement Title**
HMTA-8002	HLS-HMTA-0150	Volume for Crewmember Accommodation
HMTA-8003	HLS-HMTA-0151	Volume for Mission Accommodation
HMTA-8005	HLS-HMTA-0152	Functional Arrangement
HMTA-8006	HLS-HMTA-0153	Interference
HMTA-8007	HLS-HMTA-0154	Spatial Orientation
HMTA-8008	HLS-HMTA-0155	Consistent Orientation
HMTA-8009	HLS-HMTA-0156	Interface Orientation
HMTA-8010	HLS-HMTA-0157	Location Identifiers
HMTA-8011	HLS-HMTA-0158	Location Aids
HMTA-8012	HLS-HMTA-0159	Visual Distinctions
HMTA-8013	HLS-HMTA-0160	Internal Translation Paths
HMTA-8014	HLS-HMTA-0161	Emergency Translation Paths
HMTA-8015	HLS-HMTA-0162	Ingress, Egress and Escape Translation Paths
HMTA-8016	HLS-HMTA-0163	Translation Path Interference
HMTA-8017	HLS-HMTA-0164	Simultaneous Use
HMTA-8018	HLS-HMTA-0165	Hazard Avoidance
HMTA-8019	HLS-HMTA-0166	Path Visibility

Original Requirement ID	**SRD Requirement ID**	**Requirement Title**
HMTA-8021	HLS-HMTA-0167	Crew Ingress/Egress Translation Path in Space
HMTA-11002	HLS-HMTA-0168	Translation Paths for Suited Crewmembers
HMTA-11005	HLS-HMTA-0169	EVA Translation Path Hazard Avoidance
HMTA-8022a	HLS-HMTA-0170	Hatches - Initial
HMTA-8022	HLS-HMTA-0171	Hatch Cover and Door Operation without Tools
HMTA-8023	HLS-HMTA-0172	Unlatching Hatch Covers
HMTA-8024	HLS-HMTA-0173	Hatch Cover and Door Operating Times
HMTA-8025	HLS-HMTA-0174	Hatch Cover and Door Operating Force
HMTA-8026	HLS-HMTA-0175	Hatch Cover and Door Gravity Operations
HMTA-8027	HLS-HMTA-0176	Hatch Size and Shape
HMTA-8028	HLS-HMTA-0177	Pressure Equalization across the Hatch
HMTA-8029	HLS-HMTA-0178	Visibility across the Hatch
HMTA-8030	HLS-HMTA-0179	Hatch Cover and Door Interference
HMTA-8031	HLS-HMTA-0180	Hatch Cover Closure and Latching Status Indication
HMTA-8032	HLS-HMTA-0181	Hatch Cover Pressure Indication
HMTA-8033a	HLS-HMTA-0182	Restraints
HMTA-8033	HLS-HMTA-0183	Crew Restraint Provision

Original Requirement ID	SRD Requirement ID	Requirement Title
HMTA-8034	HLS-HMTA-0184	Crew Restraint Design
HMTA-8035	HLS-HMTA-0185	Crew Restraint Posture Accommodation
HMTA-8036	HLS-HMTA-0186	Crew Restraint Interference
HMTA-8037	HLS-HMTA-0187	Crew Restraints for Controls Operation
HMTA-11012	HLS-HMTA-0188	Restraints for Suited Operations – Provision
HMTA-8038a	HLS-HMTA-0189	Mobility Aids - Initial
HMTA-8038	HLS-HMTA-0190	Mobility Aid Standardization
HMTA-8039	HLS-HMTA-0191	Mobility Aid Structural Strength
HMTA-8040	HLS-HMTA-0192	Mobility Aid for Assisted Ingress and Egress
HMTA-8041	HLS-HMTA-0193	Unassisted Ingress, Egress and Escape Mobility Aids
HMTA-8042	HLS-HMTA-0194	IVA Operations Mobility Aids
HMTA-11003	HLS-HMTA-0195	Mobility Aid Provision for Suited Operations
HMTA-8045a	HLS-HMTA-0196	Viewing Exterior Operations - Initial
HMTA-8045	HLS-HMTA-0197	Window Optical Properties
HMTA-8046	HLS-HMTA-0198	Window Obstruction
HMTA-8049	HLS-HMTA-0199	Window Light Blocking
HMTA-8050	HLS-HMTA-0200	Window Accessory Replacement/Operation without Tools

Original Requirement ID	**SRD Requirement ID**	**Requirement Title**
HMTA-8051a	HLS-HMTA-0201	Spacecraft Lighting - Initial
HMTA-8051	HLS-HMTA-0202	Illumination Levels
HMTA-8052	HLS-HMTA-0203	Exterior Lighting
HMTA-8053	HLS-HMTA-0204	Emergency Lighting
HMTA-8059	HLS-HMTA-0205	Lighting Chromaticity
HMTA-8060	HLS-HMTA-0206	Lighting Color Accuracy
HMTA-8055	HLS-HMTA-0207	Circadian Entrainment
HMTA-8056	HLS-HMTA-0208	Lighting Controls
HMTA-8057	HLS-HMTA-0209	Lighting Adjustability
HMTA-8058	HLS-HMTA-0210	Uniformity, Glare, & Shadows
HMTA-9005a	HLS-HMTA-0211	Mechanical Hazard - Initial
HMTA-9006	HLS-HMTA-0212	Entrapment
HMTA-9007	HLS-HMTA-0213	Potential Energy
HMTA-9008	HLS-HMTA-0214	Protection from Projectiles and Structural Collapse
HMTA-9027	HLS-HMTA-0215	Protection
HMTA-9028	HLS-HMTA-0216	Isolation of Crew from Spacecraft Equipment
HMTA-9009	HLS-HMTA-0217	Sharp Corners and Edges - Fixed

Original Requirement ID	**SRD Requirement ID**	**Requirement Title**
HMTA-9010	HLS-HMTA-0218	Protection from Functionally Sharp Items
HMTA-9011	HLS-HMTA-0219	Sharp Corners and Edges - Loose
HMTA-9012	HLS-HMTA-0220	Burrs
HMTA-9013	HLS-HMTA-0221	Pinch Points
HMTA-9014	HLS-HMTA-0222	High-Temperature Exposure
HMTA-9015	HLS-HMTA-0223	Low-Temperature Exposure
HMTA-9016	HLS-HMTA-0224	Equipment Handling
HMTA-9017a	HLS-HMTA-0225	Electrical Hazard Protection - Initial
HMTA-9017	HLS-HMTA-0226	Power Interruption
HMTA-9018	HLS-HMTA-0227	Energized Status
HMTA-9019	HLS-HMTA-0228	Nominal Physiological Electrical Current Limits
HMTA-9020	HLS-HMTA-0229	Catastrophic Physiological Electrical Current Limits for all Circumstances
HMTA-9021	HLS-HMTA-0230	Catastrophic Physiological Electrical Current Limits for Startle Reaction
HMTA-9022	HLS-HMTA-0231	Body Impedance for Voltage Calculations Utilizing Electrical Current Thresholds
HMTA-9023	HLS-HMTA-0232	Leakage Currents – Equipment Designed for Human Contact
HMTA-9024a	HLS-HMTA-0233	Minimize Fluid and Gas Spill Hazards - Initial
HMTA-9024	HLS-HMTA-0417	Fluid/Gas Release

Original Requirement ID	SRD Requirement ID	Requirement Title
HMTA-9025	HLS-HMTA-0235	Fluid/Gas Isolation
HMTA-9026	HLS-HMTA-0234	Fluid/Gas Containment
HMTA-9029a	HLS-HMTA-0237	Inflight Maintenance and Assembly - Initial
HMTA-9030	HLS-HMTA-0238	Connector Spacing
HMTA-9031	HLS-HMTA-0239	Connector Actuation without Tools
HMTA-9032	HLS-HMTA-0240	Incorrect Mating, Demating Prevention
HMTA-9033	HLS-HMTA-0241	Mating, Demating Hazards
HMTA-9034	HLS-HMTA-0242	Cable Management
HMTA-9035	HLS-HMTA-0243	Cable Identification
HMTA-9036	HLS-HMTA-0244	Design for Maintenance
HMTA-9037	HLS-HMTA-0245	Commercial Off-the-Shelf Equipment Maintenance
HMTA-9038	HLS-HMTA-0246	In-Flight Tool Set
HMTA-9039	HLS-HMTA-0247	Maintenance Time
HMTA-9040	HLS-HMTA-0248	Minimizing Maintenance
HMTA-9041	HLS-HMTA-0249	Equipment Modularity
HMTA-9042	HLS-HMTA-0250	Captive Fasteners
HMTA-9044	HLS-HMTA-0251	Minimum Variety of Fasteners - System

Original Requirement ID	SRD Requirement ID	Requirement Title
HMTA-9045	HLS-HMTA-0252	Maintenance Item Location
HMTA-9046	HLS-HMTA-0253	Check and Service Point Accessibility
HMTA-9047	HLS-HMTA-0254	Maintenance Accommodation
HMTA-9048	HLS-HMTA-0255	Visual Access for Maintenance
HMTA-9049	HLS-HMTA-0256	Hand Clearance for Maintenance
HMTA-9050	HLS-HMTA-0257	Tool Clearance
HMTA-9051	HLS-HMTA-0258	Fault Detection
HMTA-9052	HLS-HMTA-0259	Failure Notification
HMTA-9053	HLS-HMTA-0260	Protective Equipment - GFE
HMTA-9054	HLS-HMTA-0261	Protective Equipment Use
HMTA-9055	HLS-HMTA-0263	Protective Equipment Automation
HMTA-9056	HLS-HMTA-0264	Use of Hearing Protection
HMTA-9058	HLS-HMTA-0266	Hearing Protection Interference
HMTA-9059	HLS-HMTA-0267	Fire Detecting, Warning, and Extinguishing
HMTA-9060	HLS-HMTA-0268	Fire Protection System Health and Status
HMTA-9061	HLS-HMTA-0269	Fire Protection System Failure Alerting
HMTA-9062	HLS-HMTA-0270	Fire Protection System Activation

Original Requirement ID	**SRD Requirement ID**	**Requirement Title**
HMTA-9063	HLS-HMTA-0271	Portable Fire Extinguishers
HMTA-9064	HLS-HMTA-0272	Emergency Equipment Accessibility
HMTA-10000	HLS-HMTA-0273	Operability
HMTA-10001	HLS-HMTA-0274	Usability Acceptance Criteria
HMTA-10002	HLS-HMTA-0275	Crew Interface Effectiveness
HMTA-10003	HLS-HMTA-0276	Crew Interface Efficiency
HMTA-10005	HLS-HMTA-0277	Crew Interfaces Standardization
HMTA-10006	HLS-HMTA-0278	Operations Nomenclature Standardization
HMTA-10007	HLS-HMTA-0279	Display Standards, Labelling Plan, and Icon Library
HMTA-10008	HLS-HMTA-0280	Units of Measure
HMTA-10009	HLS-HMTA-0281	Crew Interface Operations Standardization
HMTA-10010	HLS-HMTA-0282	Consistent Displays and Controls
HMTA-10011	HLS-HMTA-0283	Displays and Controls Commonality
HMTA-10012	HLS-HMTA-0284	Consistent Procedures
HMTA-10013	HLS-HMTA-0285	Display and Control Distinctions
HMTA-10014	HLS-HMTA-0286	Syntax Distinction
HMTA-10015	HLS-HMTA-0287	Use of Cues

Original Requirement ID	**SRD Requirement ID**	**Requirement Title**
HMTA-10016	HLS-HMTA-0288	Cue Saliency
HMTA-10017	HLS-HMTA-0289	System Health and Status
HMTA-10018	HLS-HMTA-0290	System Messages
HMTA-10019	HLS-HMTA-0291	Display Update
HMTA-10020	HLS-HMTA-0292	Missing Data Display
HMTA-10021	HLS-HMTA-0293	Control Feedback
HMTA-10022	HLS-HMTA-0294	System Feedback
HMTA-10023	HLS-HMTA-0295	Current Procedure Step
HMTA-10024	HLS-HMTA-0296	Completed Procedure Steps
HMTA-10025	HLS-HMTA-0297	View of Procedure Steps
HMTA-10026	HLS-HMTA-0298	Procedure Flexibility
HMTA-10004	HLS-HMTA-0299	Controllability and Maneuverability (Manual Control)
HMTA-10027a	HLS-HMTA-0300	Tolerate Inadvertent Operator Action
HMTA-10027	HLS-HMTA-0301	Inadvertent Operation Prevention
HMTA-10028	HLS-HMTA-0302	Inadvertent Operation Recovery
HMTA-10027b	HLS-HMTA-0303	Control for Human Error
HMTA-10027c	HLS-HMTA-0304	Design Induced Crew Error

Original Requirement ID	SRD Requirement ID	Requirement Title
HMTA-10067a	HLS-HMTA-0305	Crew Control of Vehicle
HMTA-10067	HLS-HMTA-0306	Control Shape
HMTA-10068	HLS-HMTA-0307	Control Identification
HMTA-10069	HLS-HMTA-0308	Emergency Control Coding
HMTA-10070	HLS-HMTA-0309	Control Size and Spacing
HMTA-10071	HLS-HMTA-0310	Control Arrangement and Location
HMTA-10072	HLS-HMTA-0311	Control Proximity
HMTA-10073	HLS-HMTA-0312	Control Operation during Accelerations
HMTA-10074	HLS-HMTA-0313	Control Operating Characteristics
HMTA-10075	HLS-HMTA-0314	Control Input-Response Compatibility
HMTA-10076	HLS-HMTA-0315	Control Latency
HMTA-10077	HLS-HMTA-0316	Control Resistive Force
HMTA-10078	HLS-HMTA-0317	Detent Controls
HMTA-10079	HLS-HMTA-0318	Stops Controls
HMTA-10080	HLS-HMTA-0319	Command Confirmation
HMTA-9001	HLS-HMTA-0320	Crew Interface Commonality
HMTA-9002	HLS-HMTA-0321	Differentiation

Original Requirement ID	**SRD Requirement ID**	**Requirement Title**
HMTA-9003	HLS-HMTA-0322	Routine Operation
HMTA-9004	HLS-HMTA-0323	Training Minimization
HMTA-10081	HLS-HMTA-0324	Suited Control Operations
HMTA-10082	HLS-HMTA-0325	Suited Control Spacing
HMTA-10030a	HLS-HMTA-0326	Information Design - Initial
HMTA-10030	HLS-HMTA-0327	Display and Control Location and Design
HMTA-10031	HLS-HMTA-0328	High Priority Displays and Controls
HMTA-10032	HLS-HMTA-0329	Display and Control Grouping
HMTA-10033	HLS-HMTA-0330	Display-Control Relationships
HMTA-10034	HLS-HMTA-0331	Display and Control Movement Compatibility
HMTA-10035	HLS-HMTA-0332	Display and Control Sequence of Use
HMTA-10036	HLS-HMTA-0333	Display Identifying Features
HMTA-10037	HLS-HMTA-0334	Display Area
HMTA-10038	HLS-HMTA-0335	Display Interpretation
HMTA-10039	HLS-HMTA-0336	Display Readability
HMTA-10040	HLS-HMTA-0337	Display Information
HMTA-10042	HLS-HMTA-0338	Display Information Flow

Original Requirement ID	SRD Requirement ID	Requirement Title
HMTA-10043	HLS-HMTA-0339	Display Navigation
HMTA-10044	HLS-HMTA-0340	Display Nomenclature
HMTA-10045	HLS-HMTA-0341	Display Coding Redundancy
HMTA-10046	HLS-HMTA-0342	Measurement Units
HMTA-10047	HLS-HMTA-0343	Visual Display Legibility
HMTA-10048	HLS-HMTA-0344	Visual Display Parameters
HMTA-10049	HLS-HMTA-0345	Visual Display Character Parameters
HMTA-10050	HLS-HMTA-0346	Display Font
HMTA-10052	HLS-HMTA-0347	Intelligibility of Electronically Stored Speech Messages
HMTA-10053	HLS-HMTA-0348	Sound Pressure Level
HMTA-10054	HLS-HMTA-0349	Sound Distortion Level
HMTA-10113	HLS-HMTA-0350	Information Management Capabilities – Provision
HMTA-10120	HLS-HMTA-0351	Information Management Methods and Tools
HMTA-10121	HLS-HMTA-0352	Information Management Standard Nomenclature
HMTA-10122	HLS-HMTA-0353	Information Management Compatibility
HMTA-10123	HLS-HMTA-0354	Information Management Operation Rate
HMTA-10124	HLS-HMTA-0355	Information Management Data Provision

Original Requirement ID	**SRD Requirement ID**	**Requirement Title**
HMTA-10125	HLS-HMTA-0356	Information Management Security
HMTA-10126	HLS-HMTA-0357	Information Management Ground Access
HMTA-10127	HLS-HMTA-0358	Information Capture and Transfer
HMTA-10128	HLS-HMTA-0359	Information Annotation
HMTA-10129	HLS-HMTA-0360	Information Backup and Restoration
HMTA-10130	HLS-HMTA-0361	Alternative Information Sources
HMTA-10131	HLS-HMTA-0362	Software System Recovery
HMTA-10083	HLS-HMTA-0363	Communication System Design
HMTA-10084	HLS-HMTA-0364	Communication Capability
HMTA-10085	HLS-HMTA-0365	Communication Speech Levels
HMTA-10086	HLS-HMTA-0366	Communication Operational Parameters
HMTA-10087	HLS-HMTA-0367	Communication Environmental Parameters
HMTA-10088	HLS-HMTA-0368	Communication Controls and Procedures
HMTA-10089	HLS-HMTA-0369	Communication Transmitter and Receiver Configuration
HMTA-10090	HLS-HMTA-0370	Audio Communications Quality
HMTA-10091	HLS-HMTA-0371	Speech Intelligibility
HMTA-10093	HLS-HMTA-0372	Private Audio Communication

Original Requirement ID	SRD Requirement ID	Requirement Title
HMTA-10094	HLS-HMTA-0373	Video Communications Visual Quality
HMTA-10095	HLS-HMTA-0374	Video Communications Spatial Resolution
HMTA-10096	HLS-HMTA-0375	Video Communications Temporal Resolution
HMTA-10097	HLS-HMTA-0376	Video Communications Color and Intensity
HMTA-10098	HLS-HMTA-0377	Video Communications Bit Rate
HMTA-10099	HLS-HMTA-0378	Audio-Visual Lag Time
HMTA-10055a	HLS-HMTA-0379	Caution & Warning (C&W) Annunciation - Initial
HMTA-10055	HLS-HMTA-0380	Distinguishable and Consistent Alarms
HMTA-10056	HLS-HMTA-0381	Audio Display Sound Level
HMTA-10057	HLS-HMTA-0382	Reverberation Time
HMTA-10058	HLS-HMTA-0383	Frequency
HMTA-10059	HLS-HMTA-0384	Auditory Alarms for Sleeping Crewmembers
HMTA-10114	HLS-HMTA-0385	Visual and Audio Annunciations
HMTA-10115	HLS-HMTA-0386	Set-Point Alerts
HMTA-10116	HLS-HMTA-0387	Audio Annunciation Silencing
HMTA-10117	HLS-HMTA-0388	Visual and Auditory Annunciation Failures
HMTA-10118	HLS-HMTA-0389	Visual Alerts - Red

Original Requirement ID	**SRD Requirement ID**	**Requirement Title**
HMTA-10119	HLS-HMTA-0390	Visual Alerts - Yellow
HMTA-10060	HLS-HMTA-0391	Label Provision
HMTA-10061	HLS-HMTA-0392	Label Standardization
HMTA-10062	HLS-HMTA-0393	Label Display Requirements
HMTA-10063	HLS-HMTA-0394	Label Location
HMTA-10064	HLS-HMTA-0395	Label Categories
HMTA-10065	HLS-HMTA-0396	Label Distinction
HMTA-10066	HLS-HMTA-0397	Label Font Height
HMTA-7069	HLS-HMTA-0399	Labeling of Hazardous Waste
HMTA-10100	HLS-HMTA-0400	Automated and Robotic System Provision
HMTA-10101	HLS-HMTA-0398	Automated and Robotic System Design
HMTA-10102	HLS-HMTA-0401	Robotic Control Stations - Common and Consistent
HMTA-10103	HLS-HMTA-0402	Automated and Robotic System Situational Awareness
HMTA-10104	HLS-HMTA-0403	Automation Levels
HMTA-10105	HLS-HMTA-0404	Automation Level Status Indication
HMTA-10106	HLS-HMTA-0405	Robotic System Status
HMTA-10107	HLS-HMTA-0406	Robotic System Arbitration

Original Requirement ID	**SRD Requirement ID**	**Requirement Title**
HMTA-10108	HLS-HMTA-0407	Automated and Robotic System Operation – with Communication Limitations
HMTA-10109	HLS-HMTA-0408	Automation and Robotics Shut Down Capabilities
HMTA-10110	HLS-HMTA-0409	Automation and Robotics Override Capabilities
HMTA-10111	HLS-HMTA-0410	Crew Interfaces to Robotic Systems - Spatial Disorientation
HMTA-10112	HLS-HMTA-0411	Crew Interfaces to Robotic Systems - Frames of Reference
HMTA-10500	HLS-HMTA-0412	Reusability of Habitable Vehicles (sustainability)
HLS-R-0077	HLS-R-0001	HLS Reliability - Initial
HLS-R-0401	HLS-R-0004	Failure Tolerance to Catastrophic Events
HLS-R-0077a	HLS-R-0002	HLS Reliability (cumulative) - Sustained
HLS-R-0410	HLS-SMA-0005	Mitigate Hazardous Software Behavior
HLS-R-0411	HLS-SMA-0006	Autonomous Systems
HLS-R-0413	HLS-SMA-0007	Detect and Annunciate Faults
HLS-R-0414	HLS-SMA-0008	Monitor Controls and Inhibits
HLS-R-0415	HLS-SMA-0009	Health and Status Data for Anomaly Resolution
HLS-R-0418	HLS-SMA-0010	Manual Override of Higher-Level Software Control/Automation
HLS-R-0419**a**	HLS-SMA-0011	Maintainability-Initial
HLS-R-0400	HLS-SMA-0014	Control Critical Hazards

Original Requirement ID	SRD Requirement ID	Requirement Title
HLS-L2-SMA-0017	HLS-SMA-0017	Parts Policy
HLS-L2-SMA-0018	HLS-SMA-0018	General Safety Program
HLS-L2-SMA-0019	HLS-SMA-0019	Software Safety Standards
HLS-L2-SMA-0020	HLS-SMA-0020	Workmanship Standard for Polymeric Application on Electronic Assemblies
HLS-L2-SMA-0021	HLS-SMA-0021	Workmanship Standard for Crimping, Interconnecting Cables, Harnesses, and Wiring
HLS-L2-SMA-0022	HLS-SMA-0022	Workmanship Standard for Fiber Optic Terminations, Cable Assemblies, and Installation
HLS-L2-SMA-0023	HLS-SMA-0023	Implementation Requirements for NASA Workmanship Standards
HLS-L2-SMA-0024	HLS-SMA-0024	Metrology and Calibration
HLS-L2-SMA-0025	HLS-SMA-0025	Fastener Procurement, Receiving Inspection, and Storage
HLS-L2-SMA-0026	HLS-SMA-0026	Electrical, Electronic, And Electromagnetic (EEE) Parts Assurance
HLS-R-0419a	HLS-SMA-0028	Maintainability - Sustained
HLS-R-0083	HLS-SMA-0029	Disposal
HLS-R-420	HLS-SMA-0030	Micrometeoroid and Orbital Debris (MMOD)
HLS-R-0021	HLS-R-0021	HLS Landing Accuracy
HLS-R-NEW	HLS-R-0027	HLS Reliability (per Mission)- Sustained
HLS-R-0042	HLS-R-0042	Surface Operations
HLS-R-0048	HLS-R-0048	EVA Excursion Duration - Initial

Original Requirement ID	**SRD Requirement ID**	**Requirement Title**
HLS-R-0048a	HLS-R-0048a	EVA Excursion Duration - Sustained
HLS-R-0050	HLS-R-0050	EVA Excursions Per Sortie
HLS-R-0055	HLS-R-0055	HLS NRHO Insertion
HLS-R-0056	HLS-R-0056	Scientific Payload Return
HLS-R-0058	HLS-R-0058	Abort to Crewed Staging Vehicle
HLS-R-0061	HLS-R-0061	Automated Missions
HLS-R-0070	HLS-R-0070	Daylight Operations - Initial
HLS-R-0070a	HLS-R-0070a	Daylight Operations - Sustained
HLS-R-0071	HLS-R-0071	Landing Site Vertical Orientation
HLS-R-0090	HLS-R-0090	High Resolution Imagery Capability
HLS-R-0108	HLS-R-0108	Manual Control
HLS-R-0109	HLS-R-0109	Remote operations
HLS-R-0110	HLS-R-0110	Fault Isolation and Control
HLS-R-0304	HLS-R-0304	HLS Automated RPODU
HLS-R-0305	HLS-R-0305	Reusable Element Service Life
HLS-R-0306	HLS-R-0306	Surface Access - Initial
HLS-R-0306a	HLS-R-0306a	Surface Access - Sustained

Original Requirement ID	**SRD Requirement ID**	**Requirement Title**
HLS-R-0311	HLS-R-0311	HLS to Suit System
HLS-R-0311	HLS-R-0311	HLS to Suit System
HLS-R-0312	HLS-R-0312	Gateway to HLS Interface
HLS-R-0314	HLS-R-0314	Operational Cabin Pressure Range
HLS-R-0318	HLS-R-0318	HLS Operations Mass Delivery from Lunar Orbit- Initial
HLS-R-0318a	HLS-R-0318a	HLS Mass Delivery from Lunar Orbit- Sustained
HLS-R-0319	HLS-R-0319	HLS Operations Mass Delivery Return to Lunar Orbit- Initial
HLS-R-0319a	HLS-R-0319a	HLS Operations Mass Delivery Return to Lunar Orbit - Sustained
HLS-R-0322	HLS-R-0322	Quiescent Lunar Orbit Operations
HLS-R-0323	HLS-R-0323	HLS EVA Compatibility
HLS-R-0323	HLS-R-0323	HLS EVA Compatibility
HLS-R-0324	HLS-R-0324	HLS Habitation Capability - Initial
HLS-R-0324a	HLS-R-0324a	HLS Habitation Capability - Sustained
HLS-R-0356	HLS-R-0356	Scientific Payload Delivery
L2-HLS-0029	HLS-R-0029	Concurrent RF Communication

Appendix F Acronyms and Abbreviations

3D	Three-dimensional
AADA	Active/Active Docking Adaptor
AC	Alternating Current
ACGIH	American Conference of Governmental Industrial Hygienist
ALARA	As Low As Reasonably Achievable
ANSI	American National Standards Institute
ARS	Atmosphere Revitalization System
BEI	Biological Exposure Indices
C&W	Caution and Warning
CCT	Correlated Color Temperature
CDO	Cognitive Deficit Onset
CMO	Chief Medical Officer
CO2	Carbon Dioxide
ConOps	Concept of Operations
CTB	Cargo Transfer Bag
D&C	Design and Construction
DAC	Design Analysis Cycle
DC	Direct Current
DCS	Decompression Sickness
DDT&E	Design, Development, Test, and Evaluation
DNA	Dexyribonucleic Acid
DRD	Data Requirements Document
DSNE	Design Specification for Natural Environments
ECLSS	Environmental Control and Life Support System
EDDA	EMU Don/Doff Assembly
EEE or E3	Electrical, Electronic, Electromechanical
EER	Estimated Energy Requirements
EM	Electromagnetic
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EMU	Extravehicular Mobility Unit
Env.	Environment
EOM	End-of-Mission
ETA	Electronic Technicians Associations
EVA	Extravehicular Activity
FOD	Flight Operations Directorate
FOD	Foreign Object Debris
GCR	Galactic Cosmic Ray
GFE	Government Furnished Equipment
GSE	Ground Support Equipment
GW	Gateway
H/A	Human Automation
H/R	Human Robotic
HBM	Human Body Model

HEA	Human Error Analysis
HEOMD	Human Exploration and Operations Mission Directorate
HERA	Hybrid Electronic Radiation Assessor
HIDH	Human Integration Design Handbook
HITL	Human-in-the-loop
HLS	Human Landing Systems
HMTA	Health and Medical Technical Authority
HQR	Handling Qualities Rating
HRCP	Human-Rating Certification Package
HSI	Human System Integration
IASIS	International Avionics System Interoperability Standards
ICD	Interface Control Document
ICIE	International Commission on Illumination
ICSIS	International Communication System Interoperability Standards
IECLSSIS	International ECLSS Interoperability Standards
IEEE	Institute of Electrical and Electronic Engineers
IERIS	International External Robotic Interoperability Standards
IR	Infrared
IRD	Interface Requirements Document
IRSIS	International Rendezvous System Interoperability Standards
ISPSIS	International Space Power System Interoperability Standards
ISS	International Space Station
ISwSIS	International Software System Interoperability Standards
ITIS	International Thermal System Interoperability Standards
IVA	Intravehicular Activity
IVR	Intravehicular Activity support Robot
JSC	Johnson Space Center
LADTAG	Lunar Atmosphere Dust Toxicity Assessment Group
LAN	Local Area Network
LEA	Launch, Escape, and Abort
LED	Light-emitting diode
LEO	Low Earth Orbit
LMMP	Lunar Mapping and Modeling Project
LOC	Loss of Crew
LOM	Loss of Mission
LRU	Line Replacement Unit
MMH	Monomethylhydrazine
MMOD	Micrometeroid and Orbital Debris
MOR	Medical Operations Requirements
MORD	Mission Operations Requirements Document
MPE	Maximum Permissible Exposure
MUA	Materials Usage Agreement
NEDD	Natural Environments Definition for Design
NHV	Net Habitable Volume
NIOSH	National Institute of Occupational Safety and Health
NIR	Near-Infrared
NRHO	Near Rectilinear Halo Orbit

O2	Oxygen
Orb.	Orbital
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limits
PGS	Pressure Garment Subsystem
PIO2	Inspired Oxygen
PLSS	Portable Life Support System
PNP	Probability of No Penetration
POC	Point of Contact
ppCO2	Partial Pressure of Carbon Dioxide
PPE	Personal Protective Equipment
ppO2	Partial Pressure of Oxygen
Qty	Quantity
Rad.	Radiation
REID	Risk of Exposure-Induced Death
Rev	Revision
Rev.	Revision
RF	Radio-Frequency
RH	Relative Humidity
RPOD	Rendezvous, Proximity Operations, and Docking
RPODU	Rendezvous, Proximity Operations, Docking and Undocking
SA	Situational Awareness
SAS	Space Adaptation Syndrome
SDS	Safety Data Sheet
SEE	Single Event Effects
SF	Space Flight
SI	International System of Units
SLS	Space Launch System
SMA	Safety and Mission Assurance
SMAC	Spacecraft Maximum Allowable Concentrations
SMC	Space and Missile Systems
SME	Subject Matter Expert
SPE	Solar Particle Event
SPEL	Space Permissible Exposure Limits
SPL	Sound Pressure Level
SUS	Subsystem Usability Scale
TA	Technical Authority
TLI	Trans-lunar Injection
TLV	Threshold Limit Value
TBS	To Be Supplied
TPOC	Technical Point of Contact
TRN	Terrain Relative Navigation
TWFPB	Thin Walled Flexible Pressure Boundary
UHF	Ultra High Frequency
USGS	U.S. Geological Survey
UV	Ultraviolet
VCN	Verification Closure Notice

VOC	Volatile Organic Compounds
Vol	Volume
xEMU	eXploration Extravehicular Mobility Unit

Appendix G Glossary

Glossary Term	**Acronym** *(if applicable)*	**Definition for Requirements & Verification** *adopted by the ACSC HLS Program*
Abort		Same as Mission Abort. The forced early return of the crew to the crewed staging vehicle when failures or the existence of uncontrolled catastrophic hazards prevent continuation of the mission profile and a return to the crewed staging vehicle is required for crew survival.
Automated operation		A system, element, subsystem or component function performed independently of the crew or mission control.
Autonomous operation		A system, element, subsystem or component function performed by the crew independently of mission control
Berthing		To position and attach a passive spacecraft to an active spacecraft by means of tether, grapple, mooring, robotic manipulation or other electromechanical device. The term is different from docking in which both spacecraft participate in the positioning and attaching without the aid of a mechanical arm.
Catastrophic Event		*"An event resulting in the death or permanent disability of a ground closeout or flight crewmember, or an event resulting in the unplanned loss/destruction of a major element of the CTS or ISS during the mission that could potentially result in the death or permanent disability of a flight crewmember."* *Personnel: Loss of life or permanent, disabling injury* *Facilities, equipment, assets:* *Unplanned loss/destruction of:* *1. a major element of the HLS during the lunar sortie mission,* *2. the Gateway, or other visiting vehicle*

Glossary Term	**Acronym** *(if applicable)*	**Definition for Requirements & Verification** *adopted by the ACSC HLS Program*
		that could potentially result in the death or permanent disability of a flight crewmember
Control		*The ability to execute multiple system, element, subsystem or component functions simultaneously to achieve a safe change in state, phase or configuration.*
Crewed Staging Vehicle	CSV	*The vehicle from which crew and cargo are transferred to the HLS prior to a lunar sortie mission, and to which crew and cargo are transferred from the HLS after a lunar sortie mission. The Orion Multi-purpose Crew Vehicle and the Gateway orbiting lunar outpost are Crewed Staging Vehicles in the lunar exploration architecture.*
Critical Function		*"Mission capabilities or system functions that, if lost, would result in a catastrophic event or an abort."*
Critical Hazard		*"A condition that may cause a severe injury or occupational illness."* *Personnel: Crew injury or occupational illness requiring definitive/specialty hospital/medical treatment* *Facilities, equipment, assets:* *1. Loss of the HLS lunar sortie mission* *2. Loss of:* *a) a major HLS element,* *b) a Gateway element, or other visiting vehicle not critical to the mission* *c) a condition that requires safe-haven, or major damage to essential flight Assets.*

Glossary Term	**Acronym** *(if applicable)*	**Definition for Requirements & Verification** *adopted by the ACSC HLS Program*
Dock		*"Mating of chaser vehicle, under its own flight control, to target vehicle." The term differs from berthing in which the chaser vehicle does not mate under its own flight control, but under the control of a mechanical arm or other grappling device.*
Docking		"to join (two spacecraft) mechanically while in space."
Deviation		Deviations ask permission and are "*…requested* ***before*** *any applicable requirements are violated*."
Eclipse		A period in which the earth partially or completely prevents sunlight from reaching the lunar surface.
ExtraVehicular Activity Excursion	EVA	EVA excursion includes two suited crew, and begins when crew switch from HLS power to suit power, and ends when cabin repress is initiated upon return of crew.
Failure		Inability of a system, subsystem, component, or part to perform its required function within specified limits.
Failure Tolerance		The ability to sustain a certain number of failures and still retain capability.
Fault		1] An undesired system state and/or the immediate cause of failure (e.g., maladjustment, misalignment, defect, or other). The definition of the term "fault" envelopes the word "failure," since faults include other undesired events such as software anomalies and operational anomalies. [2] An inherent defect in a product which may or may not ever manifest, such as a bug in software code.

Glossary Term	**Acronym** *(if applicable)*	**Definition for Requirements & Verification** *adopted by the ACSC HLS Program*
Goal		The capability desired by the Agency for the system design to be considered functionally robust
Interface Control Documents/Databases	ICD	ICDs record the negotiated design solution agreements that meet the IRD requirements, as negotiated and between the WBS organizations representing the configuration items on each side of the interface.
Interface Requirement Document/Database	IRD	IRDs define functional interface requirements, not design solutions. *The SE&I Lead may consolidate an IRD within its corresponding ICD, if doing so improves communication and efficiency.*
Loiter		a long-term state which requires minimal maintenance and active operations, other than position and systems monitoring.
Lunar night		periods in which the surface of the moon is on the dark side of the lunar terminator
Monitor		The ability to determine where the vehicle is, what its condition is, and what it is doing.
Occultation		An event that occurs when one object is hidden by another object that passes between it and the observer. Any situation in which an object in the foreground blocks from view (occults) an object in the background. In this context, occultation is when an object on the lunar surface prevents sunlight from reaching the HLS at its landing site.

Glossary Term	**Acronym** *(if applicable)*	**Definition for Requirements & Verification** *adopted by the ACSC HLS Program*
Operate		The ability to execute individual system, element, subsystem or component functions of the vehicle to achieve a safe change in state, phase or configuration.
Program-level Assemblies	Level 2 Assemblies	Program-level Architecture & Assemblies: * Phase 1 (2024) Assembly * Phase 2 (Sustained) Assembly
Partner-level Systems	Level 3 Systems	Partner-level Systems: * Integrated Lander System * Surface Suit System * Refueling System (Phase 2)
Proximity Operations		An active operational state terminating in the physical connection of two spacecraft, at completion of a separation sequence after a close-approach for testing or experimental reasons, or at the completion of a departure sequence
Quiescent		a passive phase with no dynamic operations (e.g., RPODU, robotics, propulsion, dockings, or space walks, etc…)
Rendezvous		An operational state in which one vehicle intentionally maneuvers to intercept another to accomplish the objectives of the mission.
Rendezvous, Proximity Operations, Docking & Undocking	RPODU	A joint operation during which two spacecraft safely maneuver to approach, connect, disconnect and depart in order to fulfill the objectives of the mission.

Glossary Term	**Acronym** *(if applicable)*	**Definition for Requirements & Verification** *adopted by the ACSC HLS Program*
Remote operation		A system, element, subsystem or component function performed by mission control or by the crew of another vehicle
Sortie a.k.a. Lunar Sortie Mission	LSM	Round trip from Lunar Orbit to lunar surface.
Sortie a.k.a. Lunar Sortie Mission	LSM	LSMs are designed to ferry astronauts between the Lunar Orbit and the Lunar surface. LSMs are a distinct operational phase within the Integrated ConOps for each one of the overall Artemis missions from Earth to Moon.
Undocking		to separate (two spacecraft) mechanically while in space. The undocking mission phase occurs from when spacecraft initiate separation, until they are 10 m apart, at which point they transition to proximity operations.
Threshold		The minimum capability acceptable to the Agency for the system design to be considered functionally adequate
Waiver		Waivers are "*…requested **after** the applicable requirement has been violated*."