National Aeronautics and
Space Administration

CxP 70024

BASELINE

RELEASE DATE: DECEMBER 15, 2006

CONSTELLATION PROGRAM
HUMAN-SYSTEMS INTEGRATION REQUIREMENTS

ADL: The applicable and reference documents listed in this document may not have been developed from the approved Program ADL listing. Please review the approved ADL before use. (Reference: CxP 70013, Constellation Program Systems Engineering Management Plan, dated 8/31/06.

Glossary: The terms within this Glossary may not have been developed from the approved Program Glossary. Please review the approved Program Glossary prior to use. (Reference: CxP 70072-ANX01, Constellation Program Management Systems Plan, Annex 1: Common Glossary and Acronyms December 4, 2006 version dropped for baseline.) These listings will be validated by Program Baseline Re-sync.

Acronyms: The terms within this Acronyms listing may not have been developed from the approved Program Acronym list. Please review the approved Acronym list prior to use. (Reference: CxP 70072-ANX01, December 4, 2006 version dropped for baseline). These listings will be validated by Program Re-sync.

The electronic version is the official approved document.
Verify this is the correct version before use.

REVISION AND HISTORY PAGE

Status	Revision No.	Change No.	Description	Release Date
Baseline	-		Baseline (Reference CxCBD C000094/1-1, dated 12/14/06)	12/15/06

NOTE: Updates to this document, as released by numbered changes (Change XXX), are identified by a black bar on the right margin.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

The Human-Systems Integration Requirements (HSIR) in this document drive the design of space vehicles, their systems and equipment with which humans interface in the Constellation Program. These requirements ensure that the design of Constellation vehicles is centered around the needs, capabilities and limitations of the human.

These requirements embody the collective experience of NASA in operation of human spacecraft from Project Mercury to the International Space Station, and were derived from NASA-STD-3000, Volume I, Man-Systems Integration Standards, Revision B, 1995; JSC 26882, Space Flight Health Requirements; MIL-STD-1472F, Department of Defense Design Criteria Standard; Federal Aviation Administration Human Factors Design Standard (HF-STD-001) and other sources.

1.1 Purpose

The HSIR provides requirements to ensure proper integration of human-system interfaces. These human-system interface requirements apply to all mission phases, including pre-launch, ascent, Earth orbit, trans-lunar flight, lunar orbit, lunar landing, lunar ascent, Earth return, Earth entry, Earth landing, post-landing, and recovery.

The Constellation Program must meet NASA's Agency-level human rating requirements, which are intended to ensure crew survival without permanent disability. The HSIR provides a key mechanism for achieving human rating of Constellation systems.

1.2 Scope and Precedence

The requirements in this document are applicable to the flight vehicles CEV, CLV, CaLV and LSAM, and are also allocated to Mission Systems, Ground Operations and EVA Systems as indicated in Appendix J. A future version of this document will address other Constellation systems.

The HSIR contains those requirements specifically addressing the needs and limitations of the human, regardless of the vehicle in which they are implemented. Vehicle-specific and system-specific requirements that are the implementation of human functional requirements can be found in system requirements documents (SRDs).

The requirements in this document address the needs of the flight crew during all phases of flight.

These requirements also address the needs of ground personnel during pre-flight preparation, maintenance and post-flight activities on the flight vehicles where there is a common interface with the flight crew.

The requirements in this document address functions that are to be performed by both contractor-furnished equipment (CFE) and government-furnished equipment (GFE).

While this document contains requirements for vehicle interfaces to be used by suited crewmembers inside the vehicle, it does not cover those vehicle interfaces to be used by suited crewmembers during Extravehicular Activity (EVA) operations outside the vehicle. These may be found in CxP 70130, Extravehicular Activity (EVA) Design and Construction Specification and the EVA System interface requirements documents.

1.3 Verification

The convention used in this document to distinguish between requirements, goals, and statements of fact is as follows: “shall” is used to indicate requirements that must be implemented and verified; “should” is used to indicate goals that must be addressed by the design but do not need to be verified; and “will” is used to indicate statements of fact that do not need to be verified.

The purpose of the Rationale statements is to indicate why the requirement is needed, the basis for its inclusion in a requirements document, and to provide context and examples to stakeholders. It is important to note that the rationales are not binding and only provide supporting information.

2 DOCUMENTS

2.1 APPLICABLE DOCUMENTS

Number	Title	Rev.
CxP-70023	Constellation Program Design Specification for Natural Environments (DSNE)	8/06
JSC 20584	Spacecraft Maximum Allowable Concentrations for Airborne Contaminants	
JSC 63307	Window Constellation Optical Design Standard	Draft
AGARD-CP-472	Implications of Advanced Technologies for Air and Spacecraft Escape	4/89
CxP-70035	Portable Equipment Payloads and Cargo IRD	

3 HUMAN-SYSTEM REQUIREMENTS

3.1 ANTHROPOMETRY, BIOMECHANICS, AND STRENGTH

This section represents requirements based on the physical size, shape, reach, posture, and strength of potential crewmembers. This data is to be used to design vehicles and the hardware and equipment used therein, to accommodate the physical size, shape, reach, range of motion, and strength of crewmembers.

Crewmembers can conduct operations unsuited, pressurized suited, or unpressurized suited. An analysis of operations must be performed to identify all tasks and task conditions. (This list of tasks is referred to in this section as “planned tasks” and includes both nominal and off-nominal tasks.) Some tasks (e.g., personal hygiene) will only be conducted by an unsuited crewmember.

Other operations (e.g., pre-launch) may never be done in anything more than an unpressurized suit. The design must accommodate “worst case” conditions. For example, if it is feasible that a pressurized suited crewmember will be in a location and using equipment, then the design of equipment and location must accommodate a pressurized suited crewmember.

3.1.1 ANTHROPOMETRY

3.1.1.1 Unsuited

The vehicle shall provide fit, access, reach, view and operation of human-system interfaces in crew functional areas for unsuited crewmembers as defined in Appendix B, Tables B-1 through B-7B (TBR-006-030). [HS2001]

Rationale: The full size range of unsuited crewmember must be able to fit, reach, view, and operate all required human-system interfaces in the crew-functional areas that do not require protective suits. Since the current and future crewmembers’ body dimensions could have a wide range, it is necessary to use the full range provided in these tables to ensure crew accommodation.

3.1.1.2 Suited

The vehicle shall provide fit, access, reach, view and operation of human system interfaces in crew functional areas for pressurized-suited crewmembers as defined in Appendix B, Tables B-7A & B-7B (TBR-006-002). [HS2002]

Rationale: The full size range of suited crewmember must be able to fit, reach, view, and operate required human-system interfaces involved in planned tasks in the crew-functional areas that require protective pressurized-suits.

3.1.2 RANGE OF MOTION

3.1.2.1 Unsuited

Aspects of the vehicle with which unsuited crewmembers physically interact during planned tasks shall be within the ranges of motion provided in Tables B-8, and B-9 and B-10 (TBR-006-070) in Appendix B. [HS2003]

Rationale: All vehicle seats and restraints need to be adjustable to accommodate the crewmembers' ranges of motion defined in the tables B-8 through B-10 in Appendix B. It is expected that suited and unsuited crewmembers will have the same range of motion.

3.1.2.2 Suited

Aspects of the vehicle with which pressurized-suited crewmembers physically interact during planned tasks shall be within the ranges of motion provided in Tables B-8, and B-9 and B-10 (TBR-006-070) in Appendix B. [HS2004]

Rationale: Pressurized-suited crewmembers should not have to reposition themselves each time they manually operate and view the vehicle’s user interfaces. All vehicle seats and restraints need to be adjustable to accommodate the crewmember’s ranges of motion defined in the tables B-8 through B-10 in Appendix B. It is expected that suited and unsuited crewmembers will have the same range of motion.

3.1.3 MASS PROPERTIES

3.1.3.1 Unsuited

Aspects of the vehicle with which an unsuited crewmember physically interacts during acceleration should accommodate crewmember mass properties as defined in Appendix B, Tables B-11 through B-16 (TBR-006-067). [HS2005]

Rationale: Body support systems (seats, brackets, restraints, etc.) must accommodate forces exerted by an unsuited crewmember under all anticipated accelerations.

3.1.3.2 Suited

Aspects of the vehicle with which a pressurized-suited crewmember may physically interact during planned tasks shall accommodate the mass of the pressurized-suited crewmember provided in Table B-11 (TBR-006-067) in Appendix B. [HS2006]

Rationale: All vehicle systems with human system interfaces need to be designed such that they will not be damaged after being subjected to the forces that a large pressurized-suited crewmember can impart on that interface. Also body support systems (seats, brackets, restraints, etc.) must accommodate forces exerted by a pressurized-suited crewmember, under all anticipated acceleration and gravity environments.

3.1.4 STRENGTH

3.1.4.1 Maximum Crew Operational Loads - Unsuited

Vehicle components and equipment that are intended to be operated by unsuited crew shall withstand the forces in the "Maximum Crew Operational Loads" column of Table B-17A in Appendix B without sustaining damage. [HS2007]

Rationale: Vehicle components and equipment must be designed to withstand large forces exerted by a strong crewmember during nominal operation, without breaking. These limits are defined by the "Maximum Crew Operational Loads".

3.1.4.2 Maximum Crew Operational Loads - Suited

Vehicle components and equipment that will only be operated by the pressurized suited crew should withstand the forces in the "Maximum Crew Operational Loads" column of Table B-17B in Appendix B without sustaining damage. [HS2007B]

Rationale: Vehicle components and equipment must be designed to withstand large forces exerted by a strong crewmember during nominal operation, without breaking. These limits are defined by the "Maximum Crew Operational Loads".

3.1.4.3 Minimum Crew Operations Loads - Unsuited

Vehicle components and equipment that are intended to be operated by unsuited crew shall require forces no greater than the "Minimum Crew Operations Loads" as defined in Table B-17A in Appendix B . [HS2008]

Rationale: A weaker crewmember should be able to perform any requested tasks. These limits are defined by the Minimum Crew Operational Loads. Crit 1 load limits are for activities related to crew safety; Crit 2 load limits are for activities related to loss of mission.

3.1.4.4 Minimum Crew Operational Loads - Suited

Vehicle components and equipment that are intended to be operated by pressurized-suited crew should require forces no greater than the "Minimum Crew Operations Loads" as defined in the appropriate data in Table B-17B in Appendix B. [HS2008B]

Rationale: A weaker crewmember should be able to perform any requested tasks. These limits are defined by the Minimum Crew Operational Loads. Crit 1 load limits are for activities related to crew safety; Crit 2 load limits are for activities related to loss of mission. The strength data for pressurized suited crew is an estimate only and is dependent on the final suit configuration.

3.1.4.5 Crew-Induced Loads

Vehicle components and equipment exposed to crew contact shall withstand a crew-induced load of 262 N (59 lb_f) (TBR-006-003) over any 10 cm by 10 cm (4 in by 4 in) square, without creating a hazard to nearby equipment or crew. [HS2009]

Rationale: Vehicle components and equipment with which the crew interacts during nominal operations on-orbit must be able to withstand accidental contact by crewmembers without breaking and creating a hazard. This is not meant to cover contact with primary structure, as the loads allowed to be imparted there will be higher.

3.2 NATURAL AND INDUCED ENVIRONMENTS

3.2.1 ATMOSPHERE

This section contains requirements for the design of systems to maintain atmospheric composition and pressure limits, to monitor and control the cabin atmosphere, and to limit contaminants and toxins.

3.2.1.1 Atmospheric Quality, Nominal

3.2.1.1.1 Total Pressure

The vehicle shall maintain internal pressure to operate within 51711 Pa (7.5 psia) (387.9 mmHg) and 103421 Pa (15.0 psia) (776 mmHg). [HS3004]

Rationale: The nominal limits for total pressure are based on deliberations of the Exploration Atmospheres Working Group (EAWG), except for maximum total pressure, where the value is chosen to be high enough not to limit normal operations around 101353 pa (14.7 psia), and low enough to prevent excessive nitrogen saturation before EVA operations. The lower pressure vehicular limit will enhance operational capability for EVA, by reducing prebreathe time without impacting DCS risk, as well as potentially reduce the atmospheric consumable burden. Operating the vehicle within a narrower total pressure range is acceptable, as long as it falls within the 51711 Pa (7.5 psia) to 103421 Pa (15.0 psia) *nominal range of operations. Transient operations under pressures outside this nominal range are tolerated as per HS3005, which include suited operations and typically will fall outside the nominal.*

3.2.1.1.2 O2 Partial Pressure

The vehicle shall maintain the partial pressure of oxygen in the internal atmosphere to operate within 18616 Pa (2.70 psia) (139 mmHg) and 23442 Pa (3.44 psia) (178 mmHg). [HS3004B]

Rationale: *Keeping oxygen tension above this level of 139 mm Hg ensures that the crewmembers will be comfortable to perform on-orbit tasks requiring enhanced mental alertness and concentration and will be able to sustain physically demanding cardiopulmonary and muscular loading such as performed during countermeasure exercises or EVA, without any performance decrements or toxicity that could be induced by insufficient or excess oxygen tension. The U.S. Occupational Safety and Health Administration (OSHA) specifies that the minimum oxygen level for entry into an enclosed space is 19.5% at sea level pressure (ppO_2 148 mm Hg; equivalent 2,000 ft). 145-178 mm Hg is the range of ppO_2 available to be breathed by >80% of the world's population terrestrially, equivalent to sea level to 3,000 feet altitude. This is the ppO2 recommended for extended nominal spaceflight operations by several space biomedical sources. Joint U.S. and Russian biomedical sourcebooks recommends keeping spacecraft ppO_2 above 128 mm Hg (below the equivalent flight altitude of 2,000 m or approx. 6,000 ft.) level in order to allow the performance of physical work in the face of cardiovascular and vestibular effects due to weightlessness. Operating the vehicle within a narrower oxygen partial pressure range is acceptable, as long as it falls within the* 18616 Pa (2.70 psia) 23442 Pa (3.44 psia) *nominal range of operations.*

3.2.1.1.3 CO2 Partial Pressure

The vehicle shall maintain the partial pressure of carbon dioxide in the internal atmosphere to less than 666.61 Pa (0.100 psi) (5.0 mmHg). [HS3004C]

Rationale: *There is no minimum CO_2 atmospheric requirement for human existence, as humans produce carbon dioxide with metabolic respiration. The NASA Spacecraft Maximum Allowable Concentration (SMAC) for 30- and 180-day time weighted average (TWA) is 5.3 mm Hg, from JSC-20584 Spacecraft Maximum Allowable Concentrations for Airborne Contaminants. No performance decrements during standard operations result with inspired CO_2 levels < 666.61 Pascal (0.100 psi) (5.0 mmHg).*

3.2.1.1.4 N2 Partial Pressure

The vehicle shall maintain the partial pressure of nitrogen in the internal atmosphere between 10332 Pa (1.5 psi) (77.5 mmHg) and 82793 Pa (12 psi) (621 mmHg) for missions greater than 10 days. [HS3004D]

Rationale: *No diluent gas is required for short duration space missions or time-limited EVAs, as long as the total atmosphere meets fire safety specifications for the vehicle and the materials within. Diluent gas is required in nominal long-duration breathable atmospheres to prevent pulmonary alveolar atelectasis (in addition to reducing the ignition/flammability threshold.) The choice of diluent gas is dependent on many factors, but the human is well adapted to the presence of nitrogen since it is inert. However, nitrogen does possess the risk of evolution from the tissue and Decompression Sickness (DCS) when the individual is exposed to hypobaric conditions. Maximum: For nominal operations, the max limit for nitrogen is set to reduce excess nitrogen saturation in the event of a contingency EVA will be performed without a prolonged oxygen prebreathe. Due to its inert nature, nitrogen does not cause significant measurable physiological effects in humans until it reaches levels equivalent to several atmospheres of depth, and therefore the nitrogen narcosis limit is 395070 Pa (57.3 psi) (296 mmHg).*

3.2.1.2 Atmospheric Quality, Contingency, Off-Nominal and Suited

3.2.1.2.1 Total Pressure

The vehicle shall maintain the pressure that the crew is exposed to within the internal atmosphere during off-nominal operations within the limits shown in Table 3.2-1. [HS3005]

Rationale: *The nominal and contingency limits for total pressure are based on deliberations of the EAWG for suited operations. 20684.27 Pacal (3.0 psi) (155.15 mmHg) total pressure, assuming that the crew is at rest, on 100%* O_2*, and a mask seal without leaks, is the lowest possible contingency or EVA ops* ppO_2*2, to prevent both hypoxia and early manifestations of ebullism, as well as excess DCS risk. The maximum limit (contingency only) is based on operational vehicular capability (assuming the use of nitrogen as a diluent gas) and to limit excess nitrogen saturation that would affect DCS risk, and that would be required to operate at higher pressures without exceeding fire limits of the cabin. This limit is far below the current maximal pressure endurance for humans, based on diving exposure, which is approximately 506764.7 Pascal (73.5 psi) (3800 mmHg) [SCUBA at 313 meters of sea water; Dec 18, 2003 for less than one hour]. For suited operations (e.g. EVA or contingency IVA operations), the vehicle must be able to go to vacuum, but the pressure the crew is exposed to should not fall outside the pressure ranges stated in Table 3.2-1. If there should be a DCS event requiring treatment, then an off-nominal crew exposure pressure >117210.9 Pascal (17 psi) (879.15 mmHg) up to 156511 Pascal (22.7psi) (1173.93 mmHg) or higher may be required to treat the DCS episode for a transient exposure period and likely will be at enriched oxygen concentration.*

Table 3.2-1 - Physiological Total Pressure Limits for Crew Exposure

Total Pressure (Pascal)	*Total Pressure (psi)*	*Time*
Pressure ≤ *20684*	Pressure ≤ *3.0*	*0*
20684 < Pressure ≤ *29647*	*3.0* < Pressure ≤ *4.3*	*12 hours*
29647 < Pressure ≤ *51711*	*4.3* < Pressure ≤ *7.5*	*14 days*
103421 < Pressure ≤ *117211*	*15.0* < Pressure ≤ *17.0*	*12 hours*
Pressure > *117211*	Pressure > *17.0*	*Contingency only*

3.2.1.2.2 O2 Partial Pressure

The vehicle shall maintain oxygen partial pressure to operate within the limits defined in Table 3.2-2. [HS3005B]

Rationale: *The* ppO_2 *minimum acceptable limits defined in Table 3.2-2 are established to ensure adequate delivery of oxygen to the pulmonary alveoli from inspired oxygen tension. These limits represent the minimum* ppO_2 *required to maintain the alveolar pressure of oxygen equivalent to that of breathing air at a range of altitudes from approx. 3,000 to 10,000-foot pressure altitude, at which degradation in performance is expected to occur with acute changes. The minimum limit for O2 partial pressure of 16798.62 Pascal (2.44 psi) 126 mmHg without acclimatization is set at approximately 9,000 ft altitude equivalent. This level is set below the 10,000 ft altitude level where oxygen masks are required per FAA and DOD requirements, and to reduce the likelihood of development of acute hypoxic symptoms, like AMS (acute mountain* *sickness). With continued exposure to less oxygen than stated in the table limits, especially with increasing level of activity, a risk of acute altitude sickness may result. The limits are in accordance with international standards, and with variations in total cabin pressure affecting the partial pressure of oxygen. Russian standards for hypoxia limits, allow exposure to 15998.68 Pascal (2.32 psi) (120 mmHg) - 18665.13 Pascal (2.71 psi) (140 mmHg) O_2 for maximum 3 days. The lowest ppO_2 level in Table 3.2-2 represents an O2 equivalent altitude (breathing air) of 10,000 feet. Rapid ascents to 10,000 feet cause a mild-moderate altitude sickness incidence in 20 to 40 percent of those ascending. The risk of altitude sickness is increased principally from the reduced alveolar oxygen tension and to a lesser degree from the decrease in the ambient air pressure. The 10,000 ft. altitude equivalent (14798.78 Pascal ppO_2) represents the maximal altitude that DOD and commercial FAA pilots may fly without supplemental oxygen (accepted masking level). Molecular oxygen (O_2) can manifest toxic effects at high partial pressures. The maximum acceptable prolonged ppO_2 physiological exposure level is 23731.38 Pascal (3.44 psi) (178 mmHg) O_2. However short-term exposure to elevated ppO_2 levels are usually well tolerated, and should result in no adverse effects on crewmembers if kept within the exposure limits in the table.*

Table 3.2-2 - Partial Pressure Oxygen Physiological Limits for Crew Exposure

ppO_2 (Pascal)	ppO_2 (mmHg)	ppO_2 (psi)	Maximum time allowed
$ppO_2 > 82737$	$ppO_2 > 620$	$ppO_2 > 12.0$	≤ 6 hours
$70327 < ppO_2 \leq 82737$	$527 < ppO_2 \leq 620$	$10.2 < ppO_2 \leq 12.0$	≤ 18 hours
$60674 < ppO_2 \leq 70327$	$456 < ppO_2 \leq 527$	$8.8 < ppO_2 \leq 10.2$	≤ 24 hours
$33095 < ppO_2 \leq 60674$	$251 < ppO_2 \leq 456$	$4.8 < ppO_2 \leq 8.8$	≤ 48 hours
$23442 < ppO_2 \leq 33095$	$178 < ppO_2 \leq 251$	$3.4 < ppO_2 \leq 4.8$	≤ 14 days
$18616 < ppO_2 \leq 23442$	$139 < ppO_2 \leq 178$	$2.7 < ppO_2 \leq 3.4$	Nominal physiological range. Indefinite with no measurable impairments.
$17237 < ppO_2 \leq 18616$	$126 < ppO_2 \leq 139$	$2.5 < ppO_2 \leq 2.7$	Indefinite with measurable performance decrements until acclimatized (after 3 days).
$15168 < ppO_2 \leq 17237$	$112 < ppO_2 \leq 126$	$2.2 < ppO_2 \leq 2.5$	1 hour, unless complete acclimatization, otherwise risk acute mountain sickness.
$ppO_2 \leq 15168$	$ppO_2 \leq 112$	$ppO_2 \leq 2.2$	Not allowed. Supplemental O_2 required to perform tasks without significant impairment.

Note: Pascal is the International Standard of Units (SI). Other units are for reference only.

3.2.1.2.3 CO2 Partial Pressure

The vehicle shall maintain the partial pressure of carbon dioxide in the internal atmosphere to operate as defined in Table 3.2-3. [HS3005C]

Rationale: *There is no minimum CO_2 requirement for human existence, however blood levels of CO_2 may be driven to impaired function levels by hyperventilation as observed during states of hypoxia. Maximum: The NASA SMAC for 1 hour and 24 hours TWA is 1319.89 Pascal (0.19 psi) (9.9 mmHg), from JSC-20584 Spacecraft Maximum Allowable Concentrations for Airborne Contaminants, however is 1999.84Pascal (0.29 psi) (15 mmHg) for 1 hour exposures. The US Navy allows*

2466.46 Pascal (0.358 psi) (18.5 mmHg) up to 24 hours with very mild and reversible symptoms beyond this exposure period. The constraints and actions within Table 3.2-3 were based on limits established by federal agency and national standard documents including SMACs (Spacecraft Maximum Acceptable Concentrations) and Russian GOST. The only sources of CO_2 on ISS are human respiration and combustion episodes. Rates of rise of CO_2 will be slow and predictable based on calculated respiration rates and number of crewmembers on board. High levels of CO_2 are unlikely to be reached acutely unless an off-nominal event (e.g. fire) has occurred, which will be associated with other more toxic compounds being elaborated into the common atmosphere. Humans usually can adapt to slow elevation rates of CO_2 exposure, and thereby a reduction in the number and severity of symptoms may be observed, however if the level of CO_2 reaches the levels listed in Table 3.2-3 then symptoms and/or performance decrements will be observed. There may be increased sensitivity to carbon dioxide or other atmospheric pollutants during spaceflight, relative to terrestrial conditions, associated with space adaptation syndrome or physiologic alterations associated with 0-g adaptation, hence a need to set limits more conservatively than those found in terrestrial applications. The difference between the time allowed between the local versus the module sensors is due to the local accumulation of CO_2 in various regions of the vehicle that occur, and an uncertain disparity between what is being measured at the module sensor location vs. what the crewmember is actually breathing where they are located.

Table 3.2-3 - Partial Pressure CO2 Physiological Limits for Crew Exposure

$PPCO_2$ (PASCAL)	$PPCO_2$ (MMHG) [1]	TIME ALLOWED IN AREA USING INSPIRED $PPCO_2$ [2]	TIME ALLOWED IN MODULE USING MODULE SENSOR
NOMINAL			
0 - 253	0.0 - 4.9	INDEFINITE	INDEFINITE
SUBOPTIMAL/DEGRADED			
259 - 274	5.0 - 5.3	30 DAYS	7 DAYS
275 - 305	5.4 - 5.9	7 DAYS	24 HOURS
306 - 388	6.0 - 7.5	24 HOURS	8 HOURS
389 - 512	7.6 - 9.9	8 HOURS	4 HOURS
513 - 771	10.0 - 14.9	4 HOURS	1 HOUR
772 - 1029	15.0 - 19.9	2 HOURS	30 MINUTES

1030 - 1546	20.0 - 29.9	30 MINUTES	DO NOT EXCEED
1547 - 2063	30.0- 39.9	DO NOT EXCEED	DO NOT EXCEED
2064 - 3925	40.0-75.9	DANGER ZONE	DANGER ZONE
>3925	>76.0	EMERGENCY	EMERGENCY

NOTE:

[1] PARTIAL PRESSURE OF CO2 (CARBON DIOXIDE)

[2] PARTIAL PRESSURE OF CO2 (CARBON DIOXIDE) AS MEASURED AT THE POINT OF CREWMEMBER INSPIRATION, EITHER NOSE OR MOUTH

3.2.1.3 Control

3.2.1.3.1 O2 and Total Pressure

The vehicle shall provide for the adjustment of total pressure and ppO_2 by the crew and Constellation Systems, within the ranges described in HS3004, HS3004B. [HS3001]

Rationale: *To ensure a safe habitable atmosphere for the crew when communications with Constellation Systems including other vehicles and Mission Systems, if unavailable, atmospheric parameters must be controllable by the crew.*

3.2.1.4 Display

3.2.1.4.1 Composition Reporting

The vehicle shall display measurements of total pressure, partial pressure oxygen, and partial pressure carbon dioxide to the crew. [HS3013]

Rationale: *Various procedures will require detailed knowledge by the crew of the values of total pressure, partial pressure oxygen, partial pressure carbon dioxide, and partial pressure nitrogen in the vehicle's atmosphere. Examples may include ISS docking, contingency EVA pre-breathe, and loss of pressure procedures.*

3.2.1.5 Alerting

3.2.1.5.1 Composition Alerting

The vehicle shall generate an alert when total pressure, ppO_2, $ppCO_2$, or ppN_2 exceed the limits specified by HS3004, HS3004B, HS3004C, HS3004D, HS3005, HS3005B, and HS3005C. [HS3014]

Rationale: *Various procedures (e.g. a loss of pressure emergency procedure) will be initiated based on the values of major constituents in the vehicle's atmosphere. Alerting removes the need for the crew to constantly monitor these atmospheric parameters during periods when there is no communications with Mission Operations: during communication outages or loss-of-signal.*

3.2.1.6 Contaminants

3.2.1.6.1 Fungal

The vehicle shall limit the levels of fungal contaminants in the internal atmosphere below 100 colony forming units/ m^3. [HS3006]

Rationale: *Microbial limits for breathing air are designed to prevent infection. Fungal limits are consistent with those defined in SSP 50260 Rev. C: ISS Medical Operations Requirements Document (MORD).*

3.2.1.6.2 Bacterial

The vehicle shall limit the levels of bacterial contaminants in the internal atmosphere below 1000 colony forming units/ m^3. [HS3006B]

Rationale: *Microbial limits for breathing air are designed to prevent infection. Bacterial limits are consistent with those defined in SSP 50260 Rev. C: ISS Medical Operations Requirements Document (MORD).*

3.2.1.6.3 Particulate

The vehicle shall limit the concentration in the cabin atmosphere of particulate matter ranging from 0.5 microns to 100 microns in aerodynamic diameter to <0.2 mg/m^3. [HS3006C]

Rationale: *Inhalation of particulates can cause irritation of the respiratory system. Limits for particulates are based on OSHA standards.*

3.2.1.6.4 Lunar Dust

The vehicle shall limit the levels of lunar dust contaminants of less than 10 micron size (TBR-006-004) in the internal atmosphere below 0.05 mg/m^3 (TBR-006-005). [HS3006D]

Rationale: *Lunar dust poses a hazard in addition to that from particulates. This limit is based on minimum expected permissible limit, as estimated by the Lunar Atmosphere Dust Toxicity Advisory Group (LADTAG). The final value for this lunar dust limit will be provided by the LADTAG in 2007.*

3.2.1.7 Gaseous Pollutants

3.2.1.7.1 Gaseous Pollutants Limits

The vehicle shall limit gaseous pollutants in the habitable volume to below concentrations described in JSC-20584, Spacecraft Maximum Allowable Concentrations (SMAC) for Airborne Contaminants. [HS3007]

Rationale: *Safe air pollutant levels are established specifically for human-rated space vehicles by the JSC Toxicology Group in cooperation with a subcommittee of the National Research Council Committee on Toxicology. Design consideration and analysis which have been used previously to achieve the values in JSC-20584 are outlined in NASA/TP-1998-207978 (1998) Elements of Spacecraft Cabin Air Quality Design. Historical methods to achieve these values included a combination of air scrubbing, materials control (e.g. using NASA-STD-6001), and containment of system chemicals.*

3.2.1.8 Rate of Change of Pressure

3.2.1.8.1 Rate of Change of Pressure Limits

The vehicle shall limit the rate of change of total internal pressure to between -206842 Pascal (–30 psi) (-1552 mmHg)/min and 93079 Pascal (+13.5 psi) (698 mmHg)/min during nominal operations when crewmembers are in the vehicle. [HS3009]

Rationale: *The rate of change of pressure must be limited to prevent injury to the crew's ears and lungs during depressurization and repressurization. These are physiological limits: it is expected that pressure changes will be effected more slowly than this where possible. 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 310264 Pascal (45 psi)(2327 mmHg)/minute (100 feet/minute) descent rate allowed by the NAVY dive manual limit. The negative rate of change limit is consistent with the NAVY dive manual 66 feet/minute ascent rate allowance. This limit is for rate of change in pressure. However, the magnitude must still be limited to prevent DCS. The magnitude change allowed will be based on starting pressure and prebreathe accomplished.*

3.2.1.9 Combustion Products

3.2.1.9.1 Combustion Products Monitoring

The vehicle shall provide a real time capability to monitor and display atmospheric concentrations of the toxic combustion products, carbon monoxide (CO), hydrogen cyanide (HCN), and hydrogen chloride (HCl), in the habitable volume of the vehicle. [HS3012A]

Rationale: *Combustion events can present an immediate threat to the life of the crew because of the release of CO, HCN, and HCl. The consequences of pyrolysis events during spaceflight are significant; therefore, a means is required to manage crew exposures to toxic compounds after a fire and to assess atmospheric decontamination.*

3.2.1.9.2 Combustion Products Measurement

The vehicle shall provide a real time capability for the measurement of atmospheric concentrations of toxic combustion products in the following ranges: carbon monoxide (CO) from 5 to 500 ppm, hydrogen cyanide (HCN) from 1 to 50 ppm, and hydrogen chloride (HCl) from 1 to 50 ppm. [HS3012B]

Rationale: *The crew must be able to measure the concentrations of the combustion products listed in the requirement to determine the correct course of action after a combustion event to mitigate risk to crew health. References: TR-915-001 (WSTF, 14 may 1998) Evaluation of Compound Specific Analyzer-Combustion Products (CSA-CP), pp. 1-12; Space Physiology and Medicine (1994) Thermo-degradation of materials (pp. 147-8); ICES Paper 2005-01-2872 "An Environmental Sensor Technology Selection Process for Exploration" [Table 1].*

3.2.1.9.3 Acid Gas Monitoring

The vehicle shall provide a capability to monitor hydrogen cyanide (HCN) and hydrogen chloride (HCl) at all locations throughout the habitable volume. [HS3012C]

Rationale: Combustion events can occur in a variety of locations in spacecraft, therefore the vehicle must be able to monitor HCN and HCl at all locations throughout the habitable volume.

3.2.1.9.4 Carbon Monoxide Alert

The vehicle shall provide a system to alert the crew whenever the carbon monoxide (CO) concentrations exceed the lower limits in HS3012B. [HS3012D]

Rationale: As the consequences of pyrolysis events during spaceflight are significant, the crew must be made aware if CO levels are above acceptable levels defined in HS3012B.

3.2.1.10 Hazardous Chemicals

3.2.1.10.1 Toxic Level 3

The vehicle shall use only chemicals which are Toxic Hazard Level 3 or below, as defined in Table C-1 in Appendix C, in the habitable volume of the vehicle. [HS3015]

Rationale: Toxic hazard Level 4 compounds, which are defined Table C-1 in Appendix C, can pose an immediate risk to crew health and cannot be scrubbed from the environment. The prevention of Toxic Hazard Level 4 chemicals from being used in the habitable atmosphere will decrease the crew health risk to these chemicals.

3.2.1.10.2 Toxic Level 4

The Constellation Architecture shall prevent Toxic Hazard Level 4 chemicals, as defined in Table C-1 in Appendix C, from entering the habitable volume of the vehicle. [HS3015A]

Rationale: Toxic hazard Level 4 compounds, which are defined Table C-1 in Appendix C, can pose an immediate risk to crew health and cannot be scrubbed from the environment. These compounds includes substances that (1) are considered extremely hazardous to the crew and a release of the substance will not allow for crew survival (via escape or isolation), and/or (2) cause permanent damage to life support systems to the extent that they are unable to maintain the atmosphere at a marginally acceptable level, and/or (3) cannot be removed from the atmosphere by the life support systems or the life support systems cannot restore the atmosphere to marginally acceptable levels in one week. The prevention of Toxic Hazard Level 4 chemicals from entering the habitable atmosphere from an external source will decrease the crew health risk to these chemicals.

3.2.1.10.3 Decomposition

The vehicle shall use only chemicals which if released do not decompose into hazardous compounds that threaten crew health during all phases of operations as described in Material Usage Agreement (MUA) documents. [HS9037]

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

3.2.1.11 Crew Protection

3.2.1.11.1 Personal Protective Equipment

The vehicle shall provide personal protective equipment (PPE) for each crewmember in the event of an emergency. [HS3016]

Rationale: Spaceflight experience has shown that all airborne toxic risks cannot be completely controlled; therefore the crew must have access to individual protective equipment in the event of failure of other controls. This equipment may include but is not limited to masks, goggles, gloves, eyewash, and contingency breathing apparatus. Reference SSP50653-1, Basic Provisions on Crew Actions in the Event of a Toxic Release on the ISS, Section 13.0 "Personal Protective Equipment", p. 33. In an emergency, this equipment must be near-to-hand, and quickly accessible.

3.2.1.11.2 Contingency Breathing Apparatus

The vehicle shall provide each member of the crew a contingency breathing apparatus, which provides breathable air that meets the quality specifications defined in HS3004B, HS3004C and HS3004D. [HS3017A]

Rationale: In the case of a medical or off-nominal condition, each crewmember will require delivery of an uncontaminated and appropriate oxygen containing breathing gas.

3.2.1.11.3 Crew Communication

The vehicle shall provide voice communication between all crewmembers when wearing the contingency breathing apparatus. [HS3017]

Rationale: Wearing a contingency breathing apparatus may hinder clear communication between crewmembers, which is essential during an emergency.

3.2.1.11.4 Mission Systems Communication

The vehicle shall provide voice communication between the crew and Mission Systems when wearing the contingency breathing apparatus. [HS3017B]

Rationale: Wearing a contingency breathing apparatus may hinder clear communication between the crew and Mission Systems, which is necessary to provide vehicle and crew status.

3.2.2 POTABLE WATER

3.2.2.1 Quality

3.2.2.1.1 Physiochemical Limits

The vehicle shall provide potable water at or below the physiochemical limits of Table 3.2-4 at the point of crew consumption. [HS3019]

Rationale: Safe water pollutant levels have been either established specifically for human-rated space vehicles by the JSC Toxicology Group in cooperation with a subcommittee of the National Research Council Committee on Toxicology or are based on maximum contaminant levels (MCLs) established by the United States Environmental Protection Agency. Point of crew consumption refers to the location from which potable water is dispensed.

Table 3.2-4 - Potable Water Physiochemical Limits

Taste	3	TTN
Odor	3	TON
Turbidity	1	NTU
Color, True	15	PCU
Free & Dissolved Gas[1]	5	%
pH	5.5 - 9.0	N/A
Chemical		
Ammonia[2]	1	mg/L
Antimony	0.006	mg/L
Arsenic	0.01	mg/L
Barium[2]	10	mg/L
Cadmium[2]	0.022	mg/L
Chloride	250	mg/L
Chlorine	4	mg/L
Chromium	0.05	mg/L
Copper	1.0	mg/L
Cyanide	0.2	mg/L
Fluoride	2	mg/L
Iron	0.3	mg/L
Lead	0.05	mg/L
Manganese[2]	0.3	mg/L
Mercury	0.002	mg/L
Nickel[2]	0.3	mg/L
Nitrate (as Nitrogen, NO_2-N)	10	mg/L
Nitrite (as Nitrogen, NO_3-N)	1.0	mg/L
Potassium	340	mg/L
Selenium	0.01	mg/L
Silver[2]	0.4	mg/L
Sulfate	250	mg/L
Total Dissolved Solids	500	mg/L
Total Iodine[3]	0.2	mg/L
Zinc[2]	2.0	mg/L
Total Organic Carbon[2]	3	mg/L
Acetone[2]	15	mg/L
Alkylamines (di)[2]	0.3	mg/L
Alkylamines (mono)[2]	2	mg/L
Alkylamines (tri)[2]	0.4	mg/L
Caprolactum[2]	100	mg/L
Chloroform[2]	6.5	mg/L
Di(2-ethylhexyl) phthalate[2]	20	mg/L
Di-n-butyl phthalate[2]	40	mg/L

Dichloromethane[2]	15	mg/L
Formaldehyde[2]	12	mg/L
Formate[2]	2500	mg/L
2-Mercaptobenzothiazole[2]	30	mg/L
Phenol[2]	4	mg/L
n-Phenyl-beta-naphthylamine[2]	260	mg/L
Semivolatile Organic Compounds listed in EPA Method 625	EPA MCL[4,5]	mg/L
Volatile Organic Compounds listed in EPA 524.2, Rev. 4	EPA MCL[4,5]	mg/L

Note:
[1] Free gas at vehicle atmospheric pressure and 98.6°F
[2] 1000-day SWEG in JSC 63414, Spacecraft Water Exposure Guidelines (SWEGs)
[3] Derived from the total iodine intake limits specified in Shuttle Flight Rule A13-30
[4] Environmental Protection Agency (EPA) Maximum Contamination Limit (MCL)
[5] If a compound has both a SWEG and EPA MCL, the SWEG value takes precedence

3.2.2.1.2 Microbial Limits

The vehicle shall provide potable water that shall maintain water quality at or below the microbial limits of Table 3.2-5 throughout the water system. [HS3019A]

Rationale: *Microbially safe water is essential to prevent infection and mitigate risk to crew health and performance. These limits are consistent with those defined by the JSC Microbiology Laboratory and in SSP 50260: ISS Medical Operations Requirements Document (MORD). On ISS, maintenance of these specifications during operation has been accomplished using flow through a 0.2 micron filter and use of a residual biocide.*

Table 3.2-5 - Potable Water Physiochemical Limits

Characteristic	Maximum Allowable	Units
Bacterial Count	50	CFU/mL
Coliform Bacteria	Non-detectable per 100 mL	-
Fungal Count	Non-detectable per 100mL	-
Parasitic Protozoa (eg, *Giardia* and *Cryptosporidium*)	0	-

3.2.2.2 Quantity

3.2.2.2.1 Potable Water On-Orbit Consumption

The vehicle shall provide a minimum of 2.5 kg (5.5 lbs) of potable water per crewmember per mission day for drinking and rehydration of food. [HS3025]

Rationale: 2.5 kg (5.5 lbs) per day is for both drinking and rehydration of food. These values are based on current ratios of thermostabilized, freeze dried, and natural form foods from the ISS menu. This amount does not include potable water requirements for other purposes, such as hygiene, pre-loading for re-entry, and post-landing consumption, and is consistent with NASA-STD-3000 Section 7. For reference, the current ratio aboard ISS is 2 liters of potable water for drinking and 0.5 liters of potable water for food hydration. If the ratio of thermostabilized, freeze-dried and natural form foods is revised, the water requirement would be adjusted appropriately.

3.2.2.2.2 Potable Water Fluid Loading

The vehicle shall provide a minimum of 2.0 kg (4.4 lbs) of potable water per crewmember for re-entry fluid loading countermeasures for End-of-Mission (EOM) and EOM+1. [HS3026]

Rationale: The 1.0 kg (2.2 lbs) quantity is based on Shuttle Aeromedical flight rule for re-entry fluid loading, which requires 48 oz. (1.5 L) for initial fluid loading, however 0.5 L of which will come from unconsumed daily water allocation per crewmember. This allocation protects for nominal EOM fluid loading plus one additional wave-off opportunity 24 hours later. Without this additional water allocation, the crew may have inadequate water available to fluid load and thus have hemodynamic compromise during and after de-orbit. Having inadequate fluid loading will almost certainly cause physiological difficulties in some, if not most, crewmembers. A small, undefinable percentage will become temporarily incapacitated and it is not inconceivable that a significantly hypovolemic crewmember in a contingency could perish when he/she otherwise would not have.

3.2.2.2.3 Potable Water Post Landing

The vehicle shall provide a minimum of 4.5 kg (9.9 lbs) of potable water per crewmember for crew consumption after landing. [HS3027]

Rationale: The 4.5 kg (9.9 lbs) quantity is based on each crewmember needing 1.0 kg (2.2 lbs) per 8-hour period, for 36 hours of post-landing recovery.

3.2.2.2.4 Potable Water Personal Hygiene Water

The vehicle shall provide a minimum of 0.4 kg (0.88 lbs) (TBR-006-006) of potable water per crewmember-day for personal hygiene. [HS3028]

Rationale: Clean water is necessary for maintaining skin, hair, and dental health of crewmembers. Some of this water quantity can be met with the water in pre-wetted towels.

3.2.2.2.5 Potable Water Rate

The vehicle shall provide potable water to the crew that will fill an a 237 milliliter (8 ounce) water bag in less than 30 seconds every minute (TBR-006-073). [HS3029]

Rationale: Crew time is at a premium on orbit. This rate ensures that the crew will be able to prepare for and perform tasks that require potable water in a reasonable amount of time. The requirement is based upon a maximum of 30 seconds between fills.

3.2.2.3 Water Temperature

3.2.2.3.1 Cold Water

The vehicle should provide cold water at a maximum temperature of 15.6 ºC (60 ºF) for missions longer than 3 days. [HS3030]

Rationale: This water is to be used to rehydrate cold drinks.

3.2.2.3.2 Hot Water

The vehicle shall provide hot water at a temperature between 68.3 ºC (155 ºF) and 79.4 ºC (175 ºF), subject to the flow rate requirement provided in HS3029. [HS3031]

Rationale: This water is to be used to rehydrate food requiring hot water. 79.4 ºC (175 ºF) water allows for the temperature of the food to still remain above 68.3 ºC (155 ºF), which prevents microbial growth. The higher water temperature also allows for better rehydration of the foods and beverages.

3.2.2.3.3 Potable Water for Personal Hygiene

The vehicle should provide personal hygiene water at a temperature between 29.4 ºC (85 ºF) and 46.1 ºC (115 ºF). [HS3032]

Rationale: This temperature range is required to support body cleansing.

3.2.2.4 Water Sampling

3.2.2.4.1 Water Sampling Pre- and Post-flight

The vehicle shall provide access to potable water systems for the collection of water samples during ground processing, in-flight, and post-landing for contamination assessment. [HS3034]

Rationale: Rigorous ground processing with pre-flight water sampling and contamination assessment prevents in-flight water quality problems, and thus minimizes the need for in-flight contamination monitoring and remediation of any water quality parameters that are out of specification. Ground-based quality analyses of in-flight and post-landing samples provide a record of crew exposure and are used to determine follow-on ground processing steps. In-flight sampling capability will also support real time contaminant monitoring and remediation of stored or regenerated water systems as needed for long-duration lunar or Mars missions.

3.2.3 THERMAL ENVIRONMENT

This section provides requirements for atmospheric temperature, humidity, dewpoint, and airflow.

3.2.3.1 Atmospheric Temperature

3.2.3.1.1 Nominal

The vehicle shall maintain the atmospheric temperature within the range of 18 ºC (64.4 ºF) to 27 ºC (80.6 ºF) during all nominal flight operations, excluding suited operations, ascent, entry, landing, and post landing. [HS3036]

Rationale: Human comfort without use of thermal protective garments requires this fairly narrow temperature range. The comfort zone 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 Thermal comfort is affected by the work rate, clothing, and state of acclimatization. Figure E-1 in Appendix E is a graphical representation of the comfort zone. The comfort zone does not include the entire range of conditions in which humans can survive indefinitely: this is a larger zone that might require active perspiration or shivering and these responses are initiated by elevated or lowered core temperatures. The graph implies minimal air movement and assumes the radiant temperature of the surroundings to be equal to the dry bulb temperature. The effects of acclimatization, work, and heavier clothing are shown as data trends by the arrows on the graph. This temperature range has been used successfully for STS and ISS vehicular operations.

3.2.3.1.2 Contingency

The Constellation Architecture shall prevent the energy stored by each crew member from exceeding the limits defined by the range, 4.7 kJ/kg (2 Btu/lb) > Q stored > -4.1 kJ/kg (-1.76 Btu/lb), during suited operations, ascent, entry, landing, post landing and off nominal flight operations, where Q stored is calculated using the 41-Node man or Wissler model. [HS3037]

Rationale: Calculation of heat storage or rejection (Q stored) is per 41-Node man or Wissler model. The Q stored equation is plotted in Appendix E Figure E-2 to graphically show the boundaries of the human heat stowage or rejection tolerance. Heat storage rationale: A vehicular cabin with excess heat load may quickly reach crew tolerance limits and impair crew performance and health. Crew impairment begins when skin temperature increases greater than 1.4 ºC (2.5 ºF) (0.6 ºC (1 ºF) core) or if pulse is greater than 140 bpm. Precise prediction of crew tolerances and time constraints for entry is not possible, therefore environmental temperature must be controlled. Appendix E Table E-1 - Core Temperature Range Limits and Associated Performance Decrements, identifies core temperature range limits and associated performance decrements. Keeping the crewmember heat storage value below the performance impairment line, allows the crew the ability to conduct even complex tasks without heat-induced degradation. In a non-acclimatized individual, water loss is approximately 0.95 L (32 oz) per hour and salt loss is approximately 2 to 3 grams (0.0044 to 0.0066 lb) per hour. In microgravity and elevated humidity, sweat forms an insulating layer over the body, further adding to the heat stress instead of relieving it. If the crewmember is in a suit, the heat load may increase rapidly. JSC thermoregulatory models (Wissler & 41-node man) simulating hot cabin entries wearing launch and entry suits with the properties of the ACES (thickness, conductance, wickability, emmissivity) predicted loss of all body cooling mechanisms. Supporting data from military aircrew protective ensembles suggests body temperature may increase more rapidly over time in ACES, compared to a shirt-sleeve environment. Heat rejection rationale: If heat is removed from the body to the point of thermogenic shivering, crew task performance will be impaired, in a similar fashion to excess heat storage. Like the condition of excess heat storage, which can be mitigated by specialized cooling garments, excess heat rejection can be mitigated to some degree by the use of insulating garments. Fig. E-2 shows the effect of tolerance to cold temperature and wind by the addition of varying degrees of thermal protecting clothing. Keeping the crewmember heat rejection value above the performance impairment line, allows the crew to conduct tasks without cold-induced degradation.

3.2.3.2 Relative Humidity

3.2.3.2.1 Relative Humidity

The vehicle shall maintain the relative humidity between 25 and 75 percent inclusive during all crewed flight operations, excluding suited operations, ascent, entry, landing, and post landing. [HS3046]

Rationale: Humidity must be maintained above this lower limit to ensure the environment is not too dry for the nominal functioning of mucous membranes and to prevent static electricity build-up within the cabin, which could pose an increased electrical hazard to the crew. Humidity must be maintained below this lower limit for crew comfort, and to limit formation of condensation.

3.2.3.3 Ventilation

3.2.3.3.1 Ventilation - In-flight

The vehicle shall maintain a ventilation rate within the internal atmosphere between 0.079 m/s (0.26 ft/s) and 0.610 m/s (2.0 ft/s) (TBR-006-071), measured more than 0.15 m (6 inches) from the vehicle walls, during the period between pre-flight hatch closure and touchdown. [HS3047]

Rationale: Crew and equipment give off heat and moisture that will lead to parameters outside the bounds of temperature 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. These values have been used on ISS.

3.2.3.3.2 Supplemental Ventilation

Local ppO2, ppCO2, and relative humidity shall be controlled as defined in Table 3.2-2, Table 3.2-3, and HS3046 for temporary maintenance activities in areas not in the normal habitable volume. [HS3050]

Rationale: The crew may be required to perform maintenance behind a panel in an area that is not part of the normal habitable volume, and which therefore does not have ventilation. Maintaining proper ventilation within the internal atmosphere is necessary to ensure that stagnant pockets do not form, and the temperature, humidity and atmospheric constituents are maintained within their appropriate ranges. Examples of historical ventilation techniques include equipment such as flexible (reconfigurable) ducting, portable fans, or diverters.

3.2.3.4 User Control

3.2.3.4.1 Temperature Set-Points

The vehicle shall provide temperature set-points in increments of 1°C (1.8° F) or less between the operational temperatures defined in HS3036. [HS3053]

Rationale: An important factor in crew comfort is the maintenance of a comfortable cabin temperature. A 1°C (1.8° F) *increment is sufficient to maintain crew comfort.*

3.2.3.4.2 Temperature Set-Point Adjust

The vehicle shall allow the crew to adjust the set-point for the atmospheric temperature within the limits defined in HS3036, with the minimal allowable range of adjustability between 21 °C (69.8 °F) (TBR-006-018) and 27 °C (80.6 °F), inclusive. [HS3051]

Rationale: *Individual comfort preferences and workload variations dictate that the set-points for the temperature can be set by the crew.*

3.2.3.4.3 Temperature Display Step Sizes

The vehicle shall display temperature with a display step size of 1°C (1.8°F). [HS3116]

Rationale: *An accurate display of temperature is required for crew reference in altering the cabin environment.*

3.2.3.4.4 Set-Point Error

The vehicle shall control temperature to +/- 1°C (1.8°F) of the set-point of the operational temperatures defined in HS3036. [HS3054]

Rationale: *Individual comfort preferences and workload variations dictate that temperature be controllable within this range as described in the paragraphs in HS3047, "Ventilation - In-flight". 1°C (1.8°F) precision is sufficient to maintain crew comfort.*

3.2.3.4.5 Seated Control

Temperature set point control shall be accessible to at least one crewmember during all nominal operations, including those when the crew is restrained. [HS3052]

Rationale: *The crew will need to control temperature during flight phases that require the crew to be restrained or seated, such as prelaunch and entry.*

3.2.3.4.6 User Control Ventilation

The vehicle shall allow the crew to adjust the ventilation delivery to the cabin. [HS3114]

Rationale: *The ability to control local cabin ventilation by adjusting the direction or speed of air flow will enable the crew to prevent exhaled, CO2-rich air from building around the head (i.e. adjust for too-little ventilation), and to prevent drying of facial mucous membranes, or reduce the acoustical noise load when needed (i.e. adjust for too much ventilation). Each constellation vehicle will have unique ventilation characteristics, therefore the specific adjustment settings will be individually defined for each vehicle, and will be stated in child requirements in lower level documents.*

3.2.3.5 Monitoring

3.2.3.5.1 Temperature Display Step

The vehicle shall display temperature with a display step size of 1 °C (1.8°F). [HS3115]

Rationale: *An accurate display of temperature is required for crew reference in altering the cabin environment.*

3.2.3.5.2 Temperature/Relative Humidity Monitoring

The vehicle shall measure, record, and display temperature and relative humidity to the crew. [HS3055]

Rationale: Temperature and humidity are critical parameters in crew health and comfort. The ability of the crew to track this data in a real time fashion prevents environmental conditions that could harm the crew or the vehicle.

3.2.4 ACCELERATION

This section presents the requirements for linear, rotational, and impact accelerations, using the coordinate system defined in Figure C-2 and Table C-2 in Appendix C.

The calculation of component linear accelerations includes:

(i) linear accelerations that are induced by rotational accelerations and (ii) centripetal accelerations that are induced by rotational velocities.

Sustained accelerations, linear or rotational, are events with a duration of greater than or equal to 0.5 seconds. Transient accelerations, linear or rotational, are events with a duration of less than 0.5 seconds.

To convert from acceleration of free fall, standard (gn) to meter per second squared (m/s2) multiply by 9.80665 (National Institute of Standards and Technology (NIST) Special Publication (SP) 811, 1995 Edition).

3.2.4.1 Sustained Linear Acceleration

These requirements apply to sustained, linear accelerations, measured at the heart.

3.2.4.1.1 Jerk

The vehicle shall prevent the crew from being exposed to a rate of change of acceleration of more than 500 g/s during any sustained acceleration event. [HS3059]

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

3.2.4.1.2 Nominal Return

The vehicle shall prevent the crew from being exposed to linear accelerations greater than those depicted by the dotted green lines in Figures 3.2-1 through 3.2-5 from mission destination to Earth landing. [HS3060]

Rationale: The dotted green lines in Figures 3.2-1 through 3.2-5 represent the maximum level of sustained acceleration allowed on a crewmember after sustained exposure to a reduced or microgravity environment, after an injury, or during an illness. After working at the mission destination, crewmembers could have degraded capabilities because of the pathophysiology of being deconditioned from exposure to reduced gravity and therefore should not be exposed to accelerations higher than those depicted by the dotted green lines in the charts. Greater exposure to g-forces could significantly affect human performance and safety. The lower dotted green limits also accommodate returning ill or injured crew members. Each axis is to be *analyzed separately, and conservatism in the limits for each axis covers any cumulative effect of acceleration in multiple axes.*

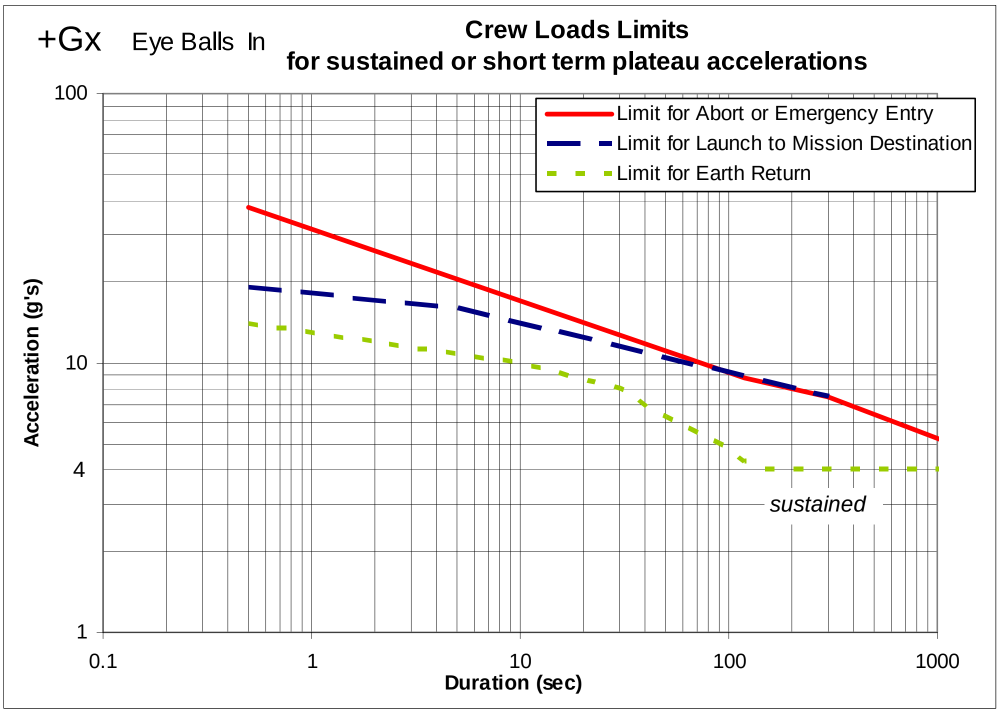


Figure 3.2-1 - + Gx Linear Sustained Acceleration Limits

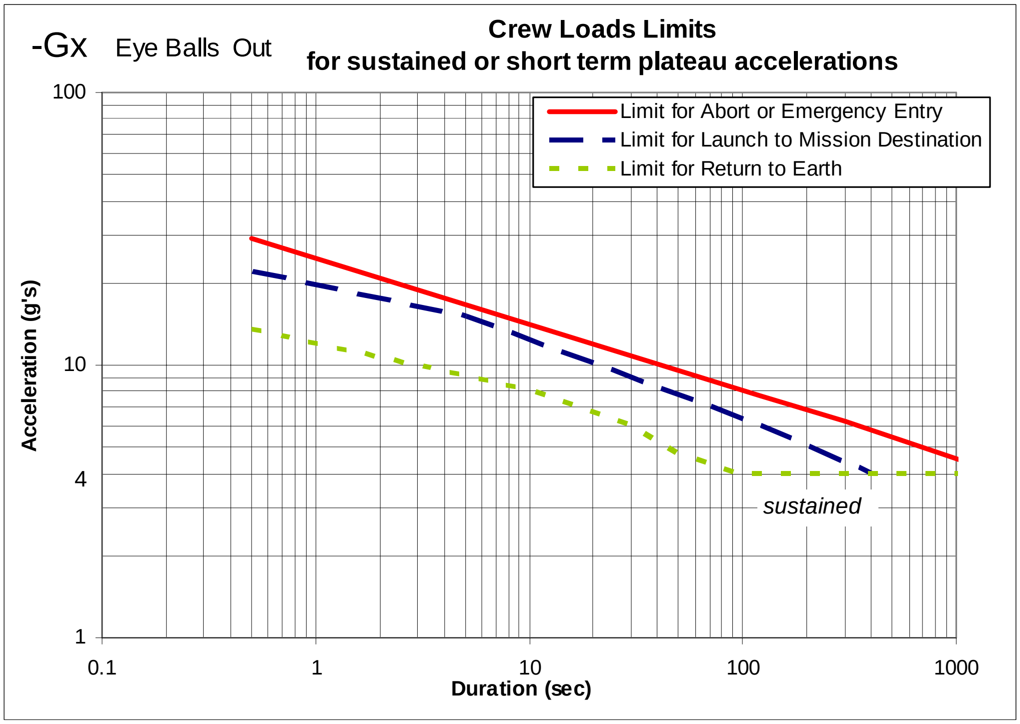


Figure 3.2-2 - - Gx Linear Sustained Acceleration Limits

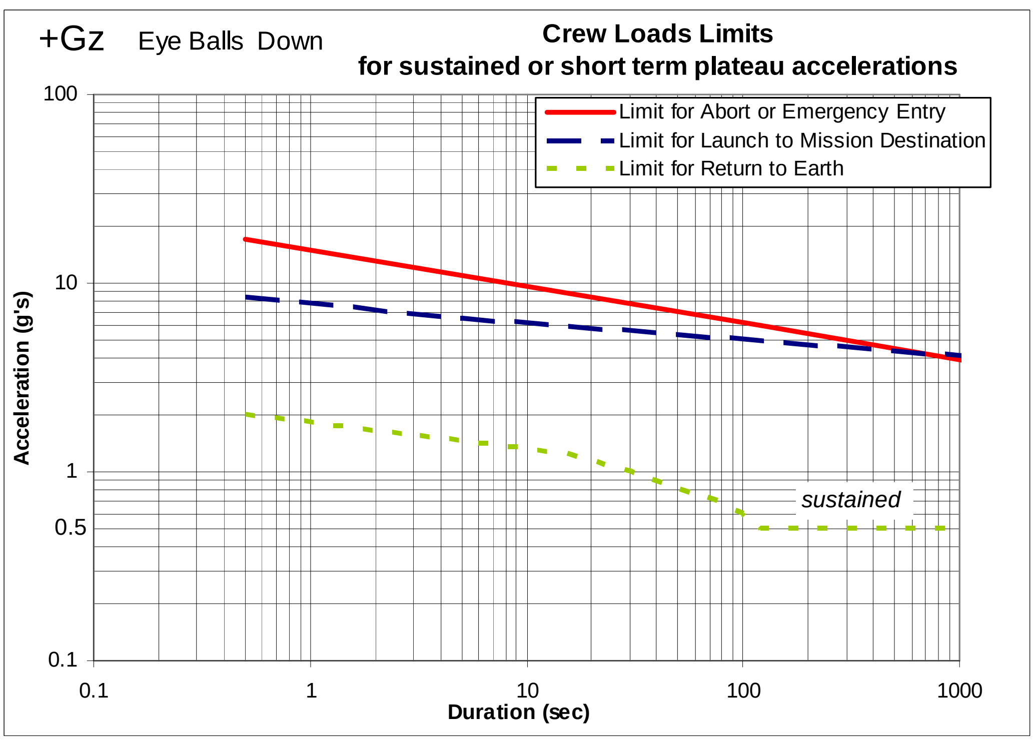


Figure 3.2-3 - +Gz Linear Sustained Acceleration Limits

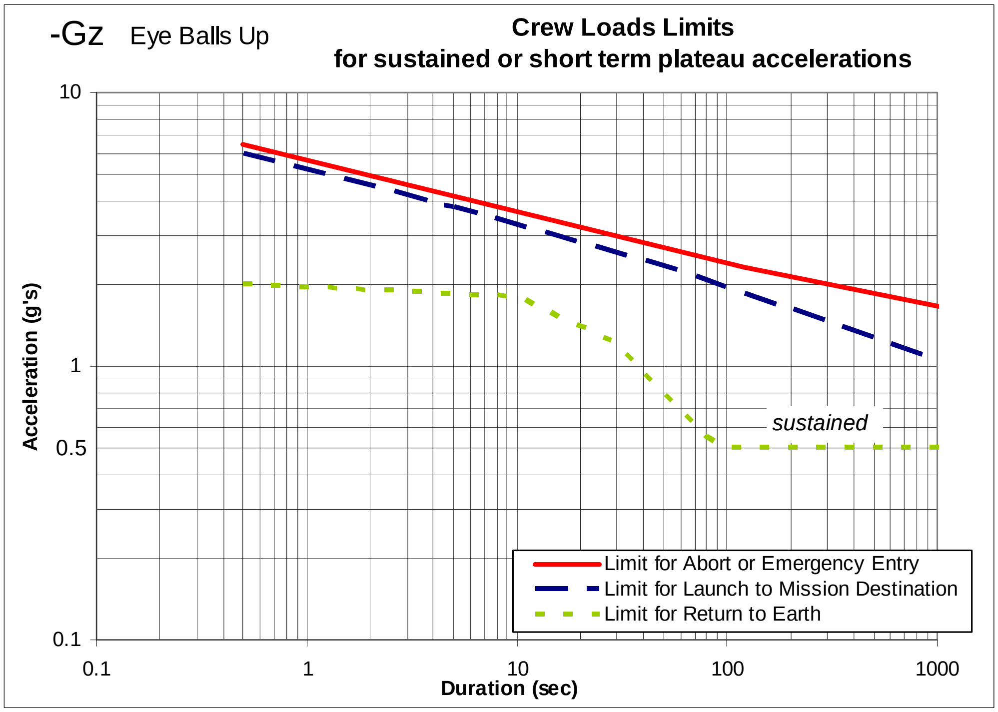


Figure 3.2-4 - -Gz Linear Sustained Acceleration Limits

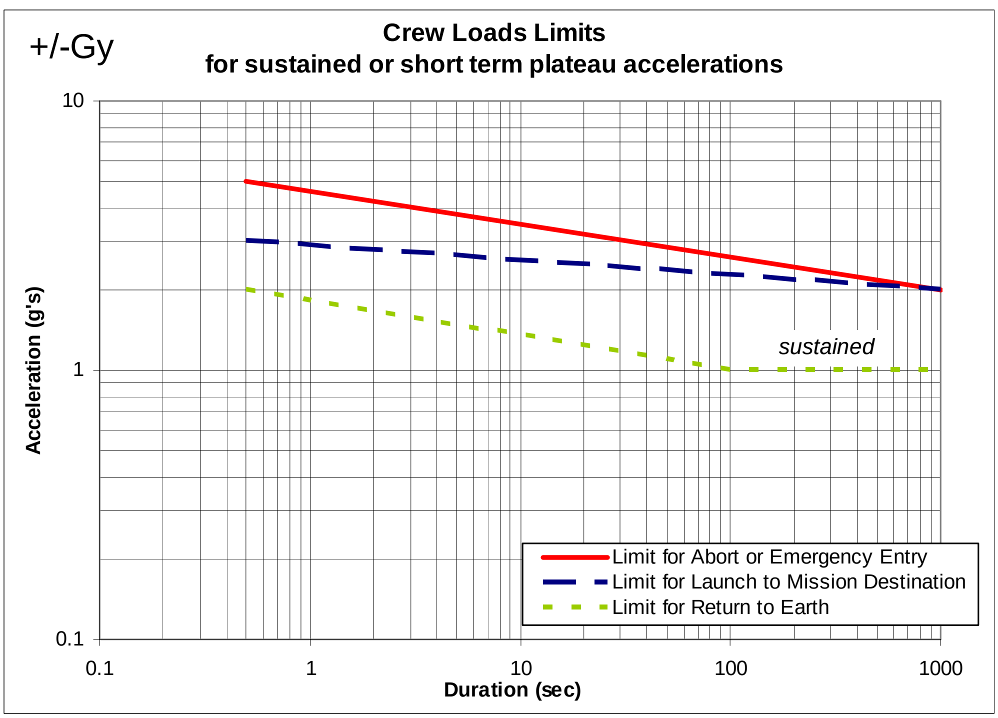


Figure 3.2-5 - +/-Gy Linear Sustained Acceleration Limits

3.2.4.1.3 Nominal Destination

The Constellation Architecture shall prevent the crew from being exposed to linear accelerations greater than those depicted by the dashed blue lines in Figures 3.2-1 through 3.2-5 from launch to mission destination. [HS3061]

Rationale: The dashed blue lines in Figures 3.2-1 through 3.2-5 represent the maximum level of sustained acceleration allowed on a conditioned crewmember under nominal conditions. These crewmembers should not be exposed to higher acceleration limits depicted by the dashed blue lines in the charts. Exposure to g-forces greater than these limits could significantly affect human performance for maneuvering and interacting with the spacecraft. Each axis is to be analyzed separately, and conservatism in the limits for each axis covers any cumulative effect of acceleration in multiple axes.

3.2.4.1.4 Ascent Abort and Off-nominal Entry

The vehicle shall prevent the crew from being exposed to linear accelerations greater than those depicted by the solid red lines in Figures 3.2-1 through 3.2-5 during a launch abort or emergency entry. [HS3062]

Rationale: The solid red lines in Figures 3.2-1 through 3.2-5 represent the maximum level of sustained acceleration allowed on a crewmember during a launch abort or emergency entry. Under these extreme conditions, it may be necessary to expose the crew to accelerations more severe than those experienced nominally (see dashed blue lines), but crewmembers should never be exposed to accelerations greater than those depicted by the solid red lines in the charts. Exceeding these elevated limits could significantly increase the risk of crew incapacitation, thereby threatening crew survival. Each axis is to be analyzed separately, and conservatism in the limits for each axis covers any cumulative effect of acceleration in multiple axes.

3.2.4.2 Transient Linear Acceleration

3.2.4.2.1 Transient Linear Accelerations

The vehicle shall limit the injury risk criterion, β, to 1.0:

$$\beta = \sqrt{\left(\frac{DR_x(t)}{DR_x^{\lim}}\right)^2 + \left(\frac{DR_y(t)}{DR_y^{\lim}}\right)^2 + \left(\frac{DR_z(t)}{DR_z^{\lim}}\right)^2}$$

DR(t)'s are calculated using the Brinkley Dynamic Response model. The spring deflection of the dynamic system along each axis is:

$$\ddot{x} + 2\xi\omega_n\dot{x} + \omega_n^{\ 2}x = A$$

where:

$\ddot{x}$ is the relative acceleration of the dynamic system mass with respect to the accelerometer location.

$\dot{x}$ is the relative velocity of the mass with respect to the accelerometer location.

x is the deflection of the mass with respect to the critical point. A positive value represents compression.

ζ is the damping coefficient ratio.

ωn is the undamped natural frequency of the dynamic system.

A is the component of the measured acceleration along the axis.

The dynamic response for each axis is given by: $DR = \omega_n^2\, x / g$

where DR is the dynamic response of the dynamic system and g is the acceleration of gravity. The following values for ω and ζ shall be used: ωnx = 62.8, ωny = 58.0, ωnz = 52.9 ζx = 0.2, ζy = 0.09, ζz = 0.224.

Under nominal conditions, limits, DRlim, are those given in the "Very low" row of Table 3.2-6, and where, under off-nominal conditions, limits are those given in the "Low" row of Table 3.2-6 for transient accelerations during parachute deployment and landing touchdown on land or water. [HS3064]

Rationale: *Utilizing the above Dynamic Response Model limits for parachute deployment and landing impacts provides the proper margins of safety (a risk of sustaining a serious or incapacitating injury of no greater than 0.5%) for a healthy deconditioned and/or an Ill/Injured crewmember. The Dynamic Response Model will provide a medical risk assessment in the event of either a CEV nominal and off-nominal failure or multiple failures. The desired Dynamic Response limits are very low (less than 0.5%) for all cases. Multiple off-nominal failures could impart risks in the medium risk and high risk categories (5% and 50% risk of sustaining a serious or incapacitating injury). These limit values are based on data from experiments in which the seat occupant was restrained to the seat and seat back by a lap belt, shoulder straps, and a strap or straps to prevent submarining of the pelvis. The restraint system was adequately pre-tensioned to eliminate slack. The +z axis limits assume that the seat cushion materials do not amplify the acceleration transmitted to the seat occupant. The +x axis limits presume that the seat occupant's head is protected by a flight helmet with a liner adequate to pass the test requirements of ANSI Z-90 (latest edition) or equivalent. These requirements assume that the crew will be similarly restrained during all events that might require application of the Brinkley model. Examples of off-nominal conditions are (i) a landing with one parachute failed, and (ii) a landing with a component failure in the landing attenuation system. The Brinkley Dynamic Response model is documented in AGARD-CP-472 "Development of Acceleration Exposure Limits for Advanced Escape Systems",*

Table 3.2-6 - Dynamic Response Limits

DR level	**X (eyeballs out, in)**		**Y (eyeballs right, left)**		**Z (eyeballs up, down)**	
	$DR_x < 0$	$DR_x > 0$	$DR_y < 0$	$DR_y > 0$	$DR_z < 0$	$DR_z > 0$
Very low (nominal)	-22.4	31	-11.8	11.8	-11	13.1
Low (off-nominal)	-28	35	-14	14	-13.4	15.2

3.2.4.3 Rotational Acceleration

3.2.4.3.1 Sustained Rotational Acceleration

The Constellation Architecture shall prevent the crew from being exposed to sustained rotational accelerations greater than 115 degrees/s^2. [HS3065]

Rationale: Crewmembers are not expected to be able to tolerate sustained rotational accelerations in excess of 115 degrees/s2 without significant discomfort and disorientation.

3.2.4.3.2 Transient Rotational Acceleration

The Constellation Architecture shall prevent the crew from being exposed to transient rotational accelerations greater than (TBD-006-052) degrees/s^2. [HS3065A]

Rationale: Crewmembers may not tolerate rotational accelerations in excess of TBD degrees/s2 without discomfort, disorientation, and/or a reduction in performance readiness. This limit applies to both nominal and abort mission phases. The TBD degrees/s2 limit is less than twice that known to be innocuous during repeated exposures in non-human primates and is two-orders of magnitude below that known to cause severe brain injury in humans. As such, this is a conservative limit that can be revisited if it proves problematic.

3.2.4.4 Rotational Rates

3.2.4.4.1 Nominal Return

The vehicle shall prevent the crew from being exposed to yaw, pitch, or roll rates greater than those depicted by the dotted green line in Figure 3.2-6 from mission destination to Earth landing. [HS3069]

Rationale: Yaw, pitch, and roll rates are rotations about the body's z-, y-, and x-axes respectively, as shown in Figure C-2. These limits apply to all three axes, and are conservative for yaw rates. Deconditioned, ill, or injured crewmembers are not expected to be able to tolerate sustained spin rates in excess of 5 to 8 RPM for extended periods of time. In addition, crewmembers outside the spin axis may experience large undesirable centripetal forces in several vectors dependent upon the spin rate, orientation, and distance from the axis of rotation. Therefore returning crewmembers (potentially deconditioned, injury, or ill) should not be exposed to rotation rates greater than the more conservative limits depicted by the dotted green line in the chart. This could significantly affect human performance on entry, landing, and egress.

3.2.4.4.2 Nominal Destination

The Constellation Architecture shall prevent the crew from being exposed to yaw, pitch, or roll rates greater than those depicted by the dashed blue lines in Figure 3.2-6 from launch to mission destination. [HS3070]

Rationale: Yaw, pitch, and roll rates are rotations about the body's z-, y-, and x-axes respectively, as shown in Figure C-2. These limits apply to all three axes, and are conservative for yaw rates. The dashed blue line in Figure 3.2-6 represents the maximum level of sustained ascent rotational rates allowed on a conditioned crewmember under nominal conditions. Under nominal conditions, conditioned crewmembers should not be exposed to rotation rates greater *than the limits depicted by the dashed blue line in the chart. This could significantly affect human performance for maneuvering and interacting with the spacecraft.*

3.2.4.4.3 Ascent Abort and Off-Nominal Entry

The vehicle shall prevent the crew from being exposed to yaw, pitch, or roll rates greater than those depicted by the solid red line in Figure 3.2-6 during a launch abort or emergency entry. [HS3071]

Rationale: Yaw, pitch, and roll rates are rotations about the body's z-, y-, and x-axes respectively, as shown in Figure C-2. These limits apply to all three axes, and are conservative for yaw rates. The solid red line in Figure 3.2-6 represents the maximum level of sustained ascent rotational rates allowed on a conditioned crewmember in a launch abort or emergency entry. Under these extreme conditions, it may be necessary to expose the crew to rotation rates more severe than those experienced nominally (see dashed blue line), but crewmembers should never be exposed to rotation rates greater than the elevated limits depicted by the solid red line in the charts. This could significantly increase the risk of crew incapacitation or survivability.

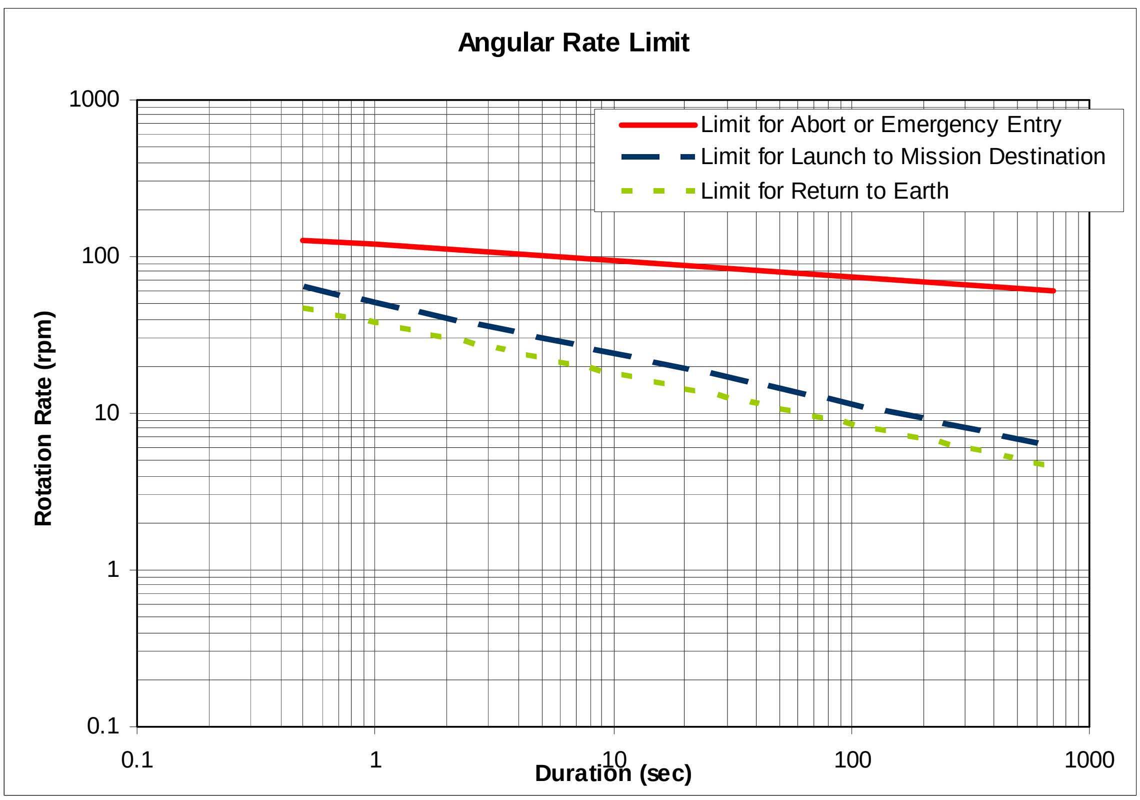


Figure 3.2-6 - Angular Rate Limits

3.2.5 VIBRATION

This section contains requirements to ensure that vibration to the crew does not cause injury during periods of acceleration, and does not negatively impact crew habitability during sustained, low-level vibration exposure.

To convert from acceleration of free fall, standard (gn) to meter per second squared (m/s2) multiply by 9.80665 (National Institute of Standards and Technology (NIST) Special Publication (SP) 811, 1995 Edition).

3.2.5.1 Health Limits

The Constellation Architecture shall limit vibration to the crew in any axis to less than 0.6 g rms integrated from 0.0167 to 80 Hz over any one-minute interval during dynamic phases of flight. [HS3105]

Rationale: Vibrations beyond 0.6 g rms for one minute are considered intolerable to humans. It is expected that internal organs could be damaged if the level of vibration or the time period for these levels were increased. In studies, subjects that were exposed to such levels for one and three minutes reported that they had to exert great effort to finish the test. Pain was reported primarily in the thorax, abdomen, and skeletal musculature. Varying effects on blood pressure and respiratory rate were also observed. The 0.6 g rms level is chosen from NASA-STD-3000 Fig 5.5.3.3.1-1 (Longditudinal Axis) using the 4-8 Hz frequency band of the 1-minute curve with the factor of two multiplier for "exposure limits." Note that the 0.6 g rms level is equivalent to adjusting the curve from NASA-STD-3000 Fig 5.5.3.3.1-1 across the

0.0167 to 80 Hz frequency range by the weighting for Wk as described in ISO standard 2631-1:1997(E) and applying the factor of two multiplier for "exposure limits." This constant level is also equivalent to adjusting the 1-minute curve from NASA-STD-3000 Fig 5.5.3.3.1-2 (Transverse Axis) across the

0.0167 to 80 Hz frequency range by the weighting for Wd and the scale factor of k= 1.4 for transverse axes as described in ISO 2631-1:1997(E), and applying the factor-of-two multiplier for "exposure limits." Finally, this level also equals the value for likely health risk with exposures less than 10 minutes provided by ISO 2631-1:1997(E), Figure B-1. Concerns by M.J. Griffin in "Handbook of Human Vibration," pp. 200-201, about higher-frequency vibrations (e.g., 15 Hz) for high amplitude and short exposure dictate that the Wk and Wd weighting should not be applied during verification of this requirement. For reference, Apollo launch data for the Command Module couch (Report SID 64-1344C Space Division of North American Rockwell, Figure 18 B), when integrated from 0.0167 to 80 Hz, without the mitigating effect of the ISO 2631-1:1997(E) weighting factors, indicates peak vibration levels of 0.77 g rms. However, this peak, which occurred ~90 sec following lift-off, lasted less than 10 sec (SID 64-1344C, Figure 9). For the worst 1-minute interval (i.e., from 50 to 110 sec following Apollo lift-off), vibrations averaged ~5 dB below peak level (SID 64-1344C, Figure 9), for an average vibration level of ~ 0.3 g rms at the couch.

3.2.5.2 Crew Sleep

The vehicle shall limit vibration to the crew in any axis to less than 0.01 g rms integrated from 0.0167 to 80 Hz averaged over an 8-hour interval during crew sleep. [HS3106]

Rationale: For long-duration exposure (> 8 hours), smaller vibrations to which the crew is exposed can adversely affect crew sleep. The level of 0.01 g rms is chosen from NASA-STD-3000 Fig 5.5.3.3.1-1 using the 4-8 Hz frequency band of the 8-hour curve and the factor of 3.15 divisor for "reduced comfort boundary." Note that this constant level is equivalent to adjusting the curve from NASA-STD-3000 Fig 5.5.3.3.1-1 across the 0.0167 to 80 Hz frequency range by the weighting for Wk described in ISO standard 2631-1:1997(E), where Wk applies to the vibration component normal to the supporting surface.

3.2.5.3 Intermittent

The vehicle shall limit vibration to the crew in any axis to less than 0.09 g rms integrated from 0.0167 to 80 Hz over any one-minute interval during crew sleep. [HS3107]

Rationale: Low-level intermittent vibration that the crew is exposed to may disturb crew sleep, and be distracting even when the crew is awake. The purpose of this requirement is to constrain the deviations around the permitted average crew sleep vibration level. Level is chosen from NASA-STD-3000 Fig 5.5.3.3.1-1 using the 4-8 Hz frequency band of the 1-minute curve and the factor of 3.15 divisor for "reduced comfort boundary." Note that this constant level is equivalent to adjusting the curve from NASA-STD-3000 Fig 5.5.3.3.1-1 across the 0.0167 to 80 Hz frequency range by the weighting for Wk described in ISO standard 2631-1:1997(E), where Wk applies to the vibration component normal to the supporting surface.

3.2.5.4 Pre-Launch, Motion Sickness

The Constellation architecture shall limit vibration to the crew to levels in any axis to less than 0.05 g rms integrated from 0.1 to 0.63 Hz over any 10-minute interval during pre-launch. [HS3108]

Rationale: Low-frequency vibration, especially in the range between 0.1 and 0.63 Hz, has the potential to cause motion sickness over relatively short exposure periods. This may be encountered while the crew is in the vehicle during the pre-launch period, given that the tall vehicle stack may be susceptible to swaying back and forth. Reducing the amount of sway will prevent the onset of motion sickness during the pre-launch phase. Note that this constant level is equivalent to adjusting the 2-hour curve from NASA-STD-3000 Fig 5.5.3.2.1-1 across the 0.1 to 0.63 Hz frequency range by the weighting for Wf described in ISO standard 2631-1:1997(E), where Wf applies to the vibration component normal to the supporting surface. The purpose of the 10-minute integration time is to constrain the deviations around the permitted average sway during a 2-hour pre-launch period.

3.2.6 ACOUSTICS

The requirements of this section will ensure that vehicle provides the crew with an acoustic environment that will not cause injury or hearing loss, interfere with voice communications, cause fatigue, or in any other way degrade overall human-machine system effectiveness.

The term "at the ear" is used for requirements for which hearing protection is allowed when meeting the requirement, while "at the head" is used for requirements for which hearing protection is not allowed. When simulation is required, the ear canal volume will be assumed to be 2.0 cc. Integrated GFE is Government Furnished Equipment that is essential to the critical functions of the vehicle.

3.2.6.1 Launch, Entry and Burn Phases

3.2.6.1.1 Noise Dose Limits

The Constellation Architecture shall limit the noise dose at the crewmember's ear calculated over any 24-hour period, to 100% or less, where the 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 in minutes, and Tn is the maximum noise exposure duration allowed, based on the specific noise level, Ln, of an exposure event in dBA, calculated using:

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

during launch, entry and burn phases including ascent abort. [HS3073]

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 OSHA limit, using the 3 dB trading rule recommended by NIOSH. The noise attenuation effectiveness of hearing protection or communications headsets may be used to satisfy this requirement. This limit does not apply to impulse noise.

3.2.6.1.2 Impulse Noise

The Constellation Architecture shall limit impulse noise at the crewmember's ear to less than 140 dB peak overall SPL, during launch, entry and burn phases including ascent abort. [HS3074]

Rationale: A limit of 140 dB peak SPL for impulse noise will prevent trauma to the hearing organs caused by impulse noise. Ref MIL-STD-1474D. The noise attenuation effectiveness of hearing protection or communications headsets may be used to satisfy this requirement.

3.2.6.1.3 Hazardous Noise Limit

The Constellation Architecture shall limit the maximum A-weighted overall sound pressure level (SPL) at the crewmember's ear to 105 dBA or less, during launch, entry, and burn phases, including ascent abort. [HS3072]

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. The noise attenuation effectiveness of hearing protection or communications headsets may be used to satisfy this requirement. This limit does not apply to impulse noise.

3.2.6.2 Orbit Phase

3.2.6.2.1 Impulse Noise

The vehicle, including integrated GFE, Portable Equipment, Payloads, and Cargo shall limit impulse noise, measured at the crewmember's head location to less than 140 dB peak SPL, during all mission phases except launch and entry. [HS3078]

Rationale: A limit of 140 dB peak SPL for impulse noise will prevent acoustic trauma. Ref. MIL-STD-1474D. The noise attenuation effectiveness of hearing protection or communications headsets may not be used to satisfy this requirement.

3.2.6.2.2 Impulse Annoyance Noise

The vehicle, including integrated GFE, Portable Equipment, Payloads, and Cargo shall limit impulse noise levels at the crewmember's head location to less than 83 dB, during crew sleep periods. [HS3079]

Rationale: Impulse noise must be limited to less than 10 dB above the background noise to avoid waking crewmembers who are sleeping. Ref. NASA-STD-3000, 5.4.3.2.3.4. Communications and alarms are not subject to this requirement.

3.2.6.2.3 Hazardous Noise Limit

The vehicle, including integrated GFE, Portable Equipment, Payloads, and Cargo shall limit the maximum A-weighted overall SPL at the crewmember's head location caused by any noise source, including voice communications and alarms, to less than 85 dBA, during all mission phases except launch, entry, and burn phases. [HS3075]

Rationale: The 85 dBA overall sound pressure level defines the hazardous noise limit at which action to reduce the noise level must be taken so that interference with voice communications and alarms, as well as increased risk for hearing loss, does not occur. This requirement is not intended for nominal hardware emissions, whose requirements are specified in HS3076 and HS3109 but to limit the sound level of sources such as alarms, communications systems, and levels that occur during maintenance activities. This requirement was taken from NASA STD 3000 5.4.3.2.1.1. The noise attenuation effectiveness of hearing protection or communications headsets may not be used to satisfy this requirement. This limit does not apply to impulse noise.

3.2.6.2.4 Sound Pressure Level (SPL) Limits - Continuous Noise

The vehicle, including integrated GFE, Portable Equipment, Payloads, and Cargo shall limit the SPLs, created by the sum of all simultaneously operating equipment, averaged over any 20 second measurement period, throughout the crew habitable volume, to the values in Table 3.2-7 or less, within each of the specified octave bands, during all mission phases except launch and entry. [HS3076]

Rationale: This NC-52 requirement will limit noise levels within the crew-habitable volume to allow for adequate voice communications and habitability during the on-orbit mission operations. The octave band sound level limits from 63 Hz to 8 kHz are equivalent to NC-52 and the 16 kHz octave band has been added to extend the range throughout the audible frequency range. This requirement does not apply to alarms, communications, items listed in Table 3.2-8, or to any noise experienced during maintenance activities. The noise attenuation effectiveness of hearing protection or communications headsets may not be used to satisfy this requirement. This limit does not apply to impulse noise.

Table 3.2-7 - Octave Band Sound Pressure Level Limits

Band center frequency (Hz)	63	125	250	500	1 k	2 k	4 k	8 k	16 k
SPL (dB)	72	65	60	56	53	51	50	49	48

3.2.6.2.5 Sound Pressure Level (SPL) Limits - Intermittent Noise

The vehicle and hardware items listed in Table 3.2-8 shall limit intermittent A-weighted overall SPL emissions, measured 0.6 m from the loudest point on the hardware, to the levels and durations in Table 3.2-9 or less, for the time noise exceeds limits in Table 3.2-7, over any 24-hour period, during all mission phases except launch, entry and burn phases. [HS3109]

Rationale: To provide for adequate speech intelligibility and habitability, levels in Table 3.2-9 will limit intermittent noise levels of specific hardware items that are inherently noisy and operate for a short time-period, where alternative means for noise control are prohibitively expensive or impractical. These sound level and operational duration limits are taken from ISS requirement SSP 57000. The noise attenuation effectiveness of hearing protection or communications headsets may not be used to satisfy this requirement. This limit does not apply to impulse noise.

Table 3.2-8 - List of Approved Vehicle or Integrated GFE Intermittent Noise Source Hardware Items

CEV toilet
LSAM toilet
Pressurized Gas Transfer Systems
Portable Equipment, Payloads and Cargo

Table 3.2-9 - Intermittent Noise A-weighted Overall Sound Pressure Level and Corresponding Operational Duration Limits (measured at 0.6 m)

Maximum Noise Duration Per 24-hour Period	L_{Amax} (dBA re 20 μPa)
8 Hours	≤ 49
7 Hours	≤ 50
6 Hours	≤ 51
5 Hours	≤ 52
4.5 Hours	≤ 53
4 Hours	≤ 54
3.5 Hours	≤ 55
3 Hours	≤ 57
2.5 Hours	≤ 58
2 Hours	≤ 60

1.5 Hours	**≤ 62**
1 Hour	**≤ 65**
30 Minutes	**≤ 69**
15 Minutes	**≤ 72**
5 Minutes	**≤ 76**
2 Minutes	**≤ 78**
1 Minute	**≤ 79**
Not Allowed	**≥ 80**

3.2.6.3 All Flight Phases

3.2.6.3.1 Tonal and Narrow-Band Noise Limits

The vehicle, including integrated GFE, shall limit the maximum SPL of narrow-band noise components and tones to at least 10 dB less than the broadband SPL of the octave band that contains the component or tone for the 1, 2, 4, and 8 kHz octave bands, and at least 5 dB less than the broadband SPL of the octave band that contains the component or tone for the 63, 125, 250 and 500 Hz octave bands. [HS3080]

Rationale: Limiting narrow band noise component and tone levels to 10 dB below the broadband level will prevent irritating and distracting acoustic conditions. Ref. NASA-STD-3000, Section 5.4.3.2.3.2.

3.2.6.3.2 Cabin Depressurization Valve Hazardous Noise Limit

The Constellation Architecture shall limit the maximum A-weighted overall SPL, at the crewmember's ear, to 105 dBA or less, during cabin depressurization valve operations. [HS3082]

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 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.

3.2.6.3.3 Cabin Depressurization Valve Noise Dose Limits

The Constellation Architecture shall limit the noise dose at the crewmember's ear, calculated over any 24-hour period, to 100% or less, where the 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. [HS3083]

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 OSHA limit, using the 3 dB trading rule recommended by NIOSH (and proposed in pending NASA hearing conservation policy NPR 1800.1, chapter 4.9). 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.*

3.2.6.3.4 Reverberation Time

The vehicle shall provide a reverberation time in the crew habitable volume of less than 0.6 seconds within the 500 Hz, 1 kHz, and 2 kHz octave bands. [HS3084]

Rationale: This 0.6 second reverberation time standard will limit degradation of speech intelligibility to no more than 10% for ideal signal-noise ratios of > 30 dB, or 15% for a signal-noise ratio of 3 dB. Reference NASA STD 3000 5.4.3.2.2.1, and, C. M. Harris, "Handbook of Acoustical Measurements and Noise Control, 3rd Ed.," p. 16.8.

3.2.6.3.5 Headsets

Crew headsets shall limit the maximum SPL at the crewmember's ear to 115 dBA or less. [HS3110]

Rationale: Noise levels above 115 dBA have been shown to produce noise-induced hearing loss. Sound levels produced by headsets are allowed to be at higher levels to overcome the noise generated during launch and descent.

3.2.6.3.6 Loudspeaker Alarm Audibility

Loudspeakers shall produce non-speech auditory annunciations that exceed the masked threshold by at least 13 dB in one or more one-third octave bands where the alarm resides, as measured at the crewmember's expected work and sleep station head locations. [HS3111]

Rationale: The 13 dB signal-to-noise ratio ensures that non-speech auditory annunciations are sufficiently salient and intelligible, according to ISO 7731. ISO 7731 is an accepted standard for ensuring the ability to detect and discriminate non-speech alarms and alerts.

3.2.6.3.7 Infrasonic Noise Limits

The vehicle shall (TBR-006-022) limit infrasonic overall SPL, at the crewmember's head location for frequencies from 1 to 16 Hz, to less than 120 dB. [HS3081]

Rationale: The 120 dB limit for infrasonic noise levels in the frequency range from 1 to 16 Hz provides for adequate habitability. The noise attenuation effectiveness of hearing protection or communications headsets may not be used to satisfy this requirement Ref. NASA-STD-3000, Section 5.4.3.2.1.4. This limit does not apply to impulse noise.

3.2.7 IONIZING RADIATION

The radiation sources in space, galactic cosmic radiation (GCR), trapped particle radiation, and solar particle events (SPE), have distinct physical and biological damage properties compared to terrestrial radiation, and thus require distinct methods to project and mitigate risks. NASA uses gender-based risk models and is developing new approaches to risk estimation.

Astronauts have been classified as radiation workers, and processes exist to protect them from excessive radiation exposure. Therefore, exposures must be kept As Low As Reasonably Achievable (ALARA).

3.2.7.1 Radiation Design Requirements

3.2.7.1.1 Radiation Design Requirements

The Constellation Architecture shall provide protection from radiation exposure consistent with ALARA principles to ensure that effective dose (tissue averaged) to any crew-member does not exceed 150 mSv for the design worst case SPE, as specified in CxP-70023, Constellation Design Specification for Natural Environments (DSNE), Section 3.3.4. [HS3085]

Rationale: The radiation design requirement of 150 mSv is imposed both to prevent clinically significant deterministic health effects, including performance degradation, sickness, or death in flight and to ensure crew career exposure limits are not exceeded with 95% confidence. The ALARA principle is a legal requirement intended to ensure astronaut safety. An important function of ALARA is to ensure 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. Radiation protection for humans in space differs from that on Earth because of the distinct types of radiation, the small population of workers, and the remote location of astronauts during spaceflight. The radiation sources in space, galactic cosmic rays (GCR), trapped particle radiation, and solar particle events (SPEs), have distinct physical and biological damage properties compared to terrestrial radiation, and the spectrum and energy of concern for humans differs from that for electronics. Radiation protection for the crew must consider this environment and these concerns. This requirement does not address GCR and trapped radiation exposure during the mission. Exposure to nominal mission exposure will be covered by a legal exposure limit.

3.2.7.2 Active Radiation Monitoring

3.2.7.2.1 Charged Particle Monitoring

The vehicle shall continuously measure and record the external fluence of particles of $Z<3$, in the energy range 30 to 300 MeV/nucleon and particles of $3 \leq Z \leq 26$, in the energy range 100 to 400 MeV/nucleon and integral fluence measurement at higher energies, as a function of energy and time, from a monitoring location that ensures an unobstructed free space full-angle field of view 1.1345 Radians (65 degrees) (TBR-006-023) or greater. [HS3086]

Rationale: The data from the charged particle monitoring is the fundamental environmental information required for radiation transport calculations and crew exposure evaluation. Given an accurately measured proton energy spectra incident on the vehicle during a solar particle event detailed crew exposure can be evaluated. This will limit the uncertainly of a single absorbed dose measurement in determining crew exposure from a solar particle event. The external fluence of particles of $Z<3$, in the energy range 30 to 300 MeV/nucleon and particles of $3 \leq Z \leq 26$, in the energy range 100 to 400 MeV/nucleon, contains a large portion of the radiation environment expected for solar particle events, trapped particle radiation, and *galactic cosmic rays. The chosen range is appropriate for the practical size and weight of radiation monitors suitable for the vehicle. 1.1345 Radians (65 degrees) (TBR-006-023) is the minimum angle required to establish a geometry factor needed to accurately measure the radiation fields.*

3.2.7.2.2 Dose Equivalent Monitoring

The vehicle shall provide an omnidirectional, portable system that can continuously measure and record the dose equivalent from charged particles with linear energy transfer 0.2 to 1000 keV/micrometer, as a function of time, at an average tissue depth of at least 2 mm. [HS3088]

Rationale: This measurement is the primary means for controlling crew exposure during missions. The current exposure limit quantity for stochastic effects (career exposure limits) is specified in dose equivalent. Tissue equivalent microdosimeters have been used extensively for crew exposure monitoring in space for this purpose. There is large set of data and calculations in the published literature that can be directly applied to crew exposure and risk determination, using tissue equivalent microdosimeters. The range of linear energy transfer of 0.2 to1000 keV/µm includes the full range expected from primary and secondary radiations of solar particle events, trapped particle radiation, and galactic cosmic rays.

3.2.7.2.3 Absorbed Dose Monitoring

The vehicle shall provide an omnidirectional, portable system that can continuously measure and record the absorbed dose from charged particles with linear energy transfer 0.2 to 1000 keV/micrometer, as a function of time, at an average tissue depth of at least 2 mm. [HS3089]

Rationale: The absorbed dose/dose equivalent instrument will be the primary instrument for controlling crew exposure during missions. The current exposure limit quantity for deterministic effects (short term exposure limits) requires the determination of absorbed dose. Tissue equivalent microdosimeters have been used extensively for crew exposure monitoring in space. There is large set of data and calculations in the published literature that can be directly applied to crew exposure and risk determination, using tissue equivalent microdosimeters. The range of linear energy transfer of 0.2 to1000 keV/micrometer includes the full range expected from primary and secondary radiations of solar particle events and galactic cosmic rays. It is expected that this requirement and the dose equivalent monitoring requirement will be met by the same instrument.

3.2.7.3 Passive Radiation Monitoring

3.2.7.3.1 Passive Radiation Monitoring Attach Points

The vehicle shall provide attach points for six passive radiation detectors inside the cabin, distributed based on the shielding distribution. [HS3090]

Rationale: Dose rate ranges inside the vehicle are crucial for calculating risks to future crews and for determining the best locations to be during contingency radiation events. Locations should be chosen using contractor produced space radiation analysis. Locations of disparate shielding distributions should be considered to monitor the complete range of crew exposure conditions. Traditionally, Velcro has been used to attach small/low mass passive dosimeters to spacecraft surfaces. The expected protrusion from the attach point of the passive detector is less than 1 cm. All the dimensions specified in the requirement and rationale are *derived from the current Government Furnished Equipment passive detectors used on the International Space Station and Space Shuttle. The quantity of 6 passive detectors was chosen based on each expected vehicle volume and vehicle shield distribution providing the best coverage throughout the volume.*

3.2.7.4 Reporting

3.2.7.4.1 Crew Reporting

The vehicle shall display the measured absorbed dose to the crew once per minute, with a latency less than five minutes. [HS3091]

Rationale: Radiation data is vital for quantifying in-flight risks to the crew. For periods of time when the crew is not in communication with Mission Operations, the crew will need to be able to ascertain the radiation conditions within the vehicle and take appropriate actions as required. The changes in the radiation environment that could cause additional crew exposure can occur in time periods as small as one minute to five minutes.

3.2.7.4.2 Mission Systems Reporting

The vehicle shall provide the measured absorbed dose to Mission Systems once per minute during periods when communication is available, with a latency less than five minutes. [HS3112]

Rationale: Radiation data is vital for quantifying in-flight risks to the crew and for allowing Mission Operations to advise the crew on appropriate action in response to an SPE. The quiescent galactic cosmic ray and trapped radiation data will be used to track the crew exposure throughout the mission as well as provide positive indication of proper health and status of the absorbed dose instrument. This will ensure instrument performance before the onset of any solar particle event that may occur.

3.2.7.4.3 Particle Archive Data

The vehicle shall provide the archive of all recorded charged particle, dose equivalent, and absorbed dose data to Mission Systems by the completion of the mission. [HS3113]

Rationale: Charged particle, dose equivalent, and absorbed dose data taken during missions will be used post mission for radiation dose/risk assessment. This data will be used determine the final dose of record for of crewmembers used to track against crew exposure limits. For the short duration missions: CEV ISS missions and Lunar Sorties, the complete data archive is only needed after the mission.

3.2.7.5 Alerting

3.2.7.5.1 Alerting

The vehicle shall alert the crew, whenever the absorbed dose rate exceeds a pre-flight programmable threshold in the range 0.02 mGy/min to 10 mGy/min for 3 consecutive readings. [HS3092]

Rationale: Should communications from the ground be interrupted or lost, the crew requires on-board warnings when the radiation environment crosses dangerous thresholds so 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.*

3.2.8 NON-IONIZING RADIATION

3.2.8.1 Radio-Frequency Radiation Limits

3.2.8.1.1 Radio-Frequency Electromagnetic Field Radiation Limits

The vehicle shall limit the crew's exposure to radio-frequency electromagnetic fields to the limits specified in Appendix C Table C-3 and Figure C-3. [HS3093]

Rationale: All devices which generate radio frequency radiation (including, but not limited to, antennas and wireless systems) must limit the amount of this radiation which the crew can be exposed to. These limits are adopted from IEEE C95.1 "Standard for Safety 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.

3.2.8.2 Laser Radiation Limits

3.2.8.2.1 Point Sources

Class 3b & 4 point source laser systems shall limit ocular exposure to the limits provided in Appendix C Table C-4 without protective equipment. [HS3094]

Rationale: This requirement limits eye exposure to both continuous and repetitively pulsed lasers in order to protect against injury to crew members' eyes. The requirement is adopted from the American Council of Governmental Industrial Hygienists as published in American Conference of Governmental Industrial Hygienists (ACGIH) Standards, "Threshold Limit Values and Biological Exposure Indices". Laser systems refers to the laser, its housing, and controls. This applies to laser systems utilized both internal and external to the vehicle.

3.2.8.2.2 Extended Sources

Class 3b & 4 extended source laser systems shall limit ocular exposure to the limits provided in Appendix C Table C-5 without protective equipment. [HS3095]

Rationale: This requirement limits eye exposure to both continuous and repetitively pulsed lasers in order to protect against injury to crewmembers' eyes. The requirement is adopted from the American Council of Governmental Industrial Hygienists as published in American Conference of Governmental Industrial Hygienists (ACGIH) Standards, "Threshold Limit Values and Biological Exposure Indices". Laser systems refers to the laser, its housing, and controls. This applies to laser systems utilized both internal and external to the vehicle.

3.2.8.2.3 Skin Exposure

Class 3b & 4 laser systems shall limit skin exposure to the limits provided in Appendix C Table C-6 without protective equipment. [HS3096]

Rationale: This requirement limits skin exposure to both continuous and repetitively pulsed lasers in order to protect against injury to crew. The requirement is adopted from the American Council of Governmental Industrial Hygienists as published in American Conference of Governmental Industrial Hygienists (ACGIH) Standards, "Threshold Limit Values and

Biological Exposure Indices". Laser systems refers to the laser, its housing, and controls. This applies to laser systems utilized both internal and external to the vehicle.

3.2.8.2.4 Selected Continuous-Wave Lasers

Laser Systems of the types specified in Appendix C Table C-7 shall limit eye and skin exposure to the limits given in Appendix C Table C-7 without protective equipment. [HS3097]

Rationale: This requirement limits skin and eye exposure to both continuous and repetitively pulsed lasers that are commonly available. The requirement is adopted from the ACGIH standards, "Threshold Limit Values and Biological Exposure Indices". These limits are derived from and therefore a subset of HS3094, HS3095, HS3096, and HS3097 . This applies to laser systems utilized both internal and external to the vehicle.

3.2.8.3 Incoherent Radiation

Requirements for limiting crew exposure to the electromagnetic spectrum from the ultraviolet (180 nm) to the far infrared (3000 nm), are derived from the methodology given in the American Conference of Governmental Industrial Hygienists (ACGIH) Standards, Threshold Limit Values and Biological Exposure Indices.

This methodology allows for the quantification of the relationship between source strength and acceptable exposure times for each of four potential injury pathways (retinal thermal injury caused by exposure to visible light, retinal photochemical injury caused by chronic exposure to blue-light, thermal injury to the ocular lens and cornea caused by infrared exposure, and exposure of the unprotected skin or eye to ultraviolet radiation). These limits do not apply to laser exposure (see laser exposure limits). The numerical values used by the ACGIH are amended for use by NASA by the insertion of a factor of 0.2 in the source term of each calculation, with the exception of the calculation for ultraviolet exposure, which is not amended. This removes the excessive margin of safety imposed by the ACGIH on general populations.

3.2.8.3.1 Retinal Thermal Injury from Visible and Near Infrared Light

3.2.8.3.1.1 Internal Spectral Radiance Limits

Window systems shall limit the internal spectral radiance Lλ at wavelengths between 385 and 1400 nm such that:

$$0.2\sum_{385}^{1400}\{L_\lambda\, R(\lambda)\Delta\lambda\} \le \frac{5}{\alpha\, t^{1/4}}$$

where Lλ is the source spectral radiance in W/(cm2•sr•nm), R(λ) is the Retinal Thermal Hazard Function given in Appendix C Table C-8, t is the viewing duration in seconds, and α is the angular subtense of the source in radians. [HS3098]

Rationale: This is to prevent retinal thermal injury from visible and near-infrared (near IR) light sources with wavelengths between 385 and 1400 nm. Proper material selection will aid in meeting requirements for both high transmittance of science windows and protection from non-ionizing radiation (this requirements). Window Systems are any stacked window configuration including both the panes and associated coatings which view outside the vehicle (to the sun).

3.2.8.3.1.2 Lighting Sources Internal Spectral Radiance Limits

Light sources in excess of (TBD-006-001) shall limit the internal spectral radiance Lλ at wavelengths between 385 and 1400 nm such that:

$$0.2\sum_{385}^{1400}\{L_\lambda \, R(\lambda)\Delta\lambda\} \le \frac{5}{\alpha\, t^{1/4}}$$

where Lλ is the source spectral radiance in W/(cm2•sr•nm), R(λ) is the Retinal Thermal Hazard Function given in Appendix C Table C-8, t is the viewing duration in seconds, and α is the angular subtense of the source in radians. [HS3098A]

Rationale: This is to prevent retinal thermal injury from visible and near-infrared (near IR) light sources with wavelengths between 385 and 1400 nm. This is applicable to both internal and external vehicle light sources. The TBD limit is a cutoff value used to reduce the number of light sources that require testing to only those that are "brighter" and more likely to cause issues. Value is still being researched.

3.2.8.3.2 Retinal Photochemical Injury from Visible Light

3.2.8.3.2.1 Small Sources

The vehicle shall limit the internal spectral irradiance Eλ at wavelengths between 305 and 700 nm for visible-light sources subtending an angle less than 11 milliradians, such that:

$$0.2\sum_{305}^{700}\{E_\lambda t B(\lambda)\Delta\lambda\} \le 10\ mJ/cm^2\ for\ t < 10^4 s$$

or

$$0.2\sum_{305}^{700}\{E_\lambda B(\lambda)\Delta\lambda\} \le 1\ \mu W/cm^2\ for\ t > 10^4 s$$

where B(λ) is the blue-light hazard function given in Appendix C Table C-8. [HS3099]

Rationale: This requirement prevents retinal photochemical injury from chronic exposure to visible-light sources with wavelengths between 305 and 700 nm.

3.2.8.3.2.2 Spectral Irradiance-Small Sources

Light sources subtending an angle less than 11 milliradians and in excess of (TBD-006-002) shall limit the internal spectral irradiance Eλ at wavelengths between 305 and 700 nm, such that:

$$0.2\sum_{305}^{700}\{E_\lambda t B(\lambda)\Delta\lambda\} \le 10\ mJ/cm^2\ for\ t < 10^4 s$$

or

$$0.2\sum_{305}^{700}\{E_\lambda B(\lambda)\Delta\lambda\} \le 1\ \mu W/cm^2\ for\ t > 10^4 s$$

where B(λ) is the blue-light hazard function given in Appendix C Table C-8. [HS3099A]

Rationale: This is to prevent retinal photochemical injury from chronic exposure to visible light sources subtending an angle less than 11 milliradians and with wavelengths between 305 and 700 nm. This is applicable to both internal and external vehicle light sources. The TBD limit is a cutoff value used to reduce the number of light sources that require testing to only those that are "brighter" and more likely to cause issues. Value is still being researched.

3.2.8.3.2.3 Large Sources

Window systems shall limit the internal spectral irradiance Eλ at wavelengths between 305 and 700 nm for visible-light sources subtending an angle greater than or equal to 11 milliradians, such that:

$$0.2\sum_{305}^{700}\{L_\lambda t B(\lambda)\Delta\lambda\} \le 100\ J/(cm^2 \cdot sr) \quad for\ t \le 10^4 s$$

or

$$0.2\sum_{305}^{700}\{L_\lambda B(\lambda)\Delta\lambda\} \le 10^{-2}\ W/(cm^2 \cdot sr) \quad for\ t > 10^4 s$$

where B(λ) is the blue-light hazard function given in Appendix C Table C-8. [HS3101]

Rationale: This requirement prevents retinal photochemical injury from chronic exposure to visible-light sources with wavelengths between 305 and 700 nm.

3.2.8.3.2.4 Spectral Irradiance-Large Sources

Light sources subtending an angle greater than or equal to 11 milliradians, in excess of (TBD-006-003) shall limit the internal spectral irradiance Eλ at wavelengths between 305 and 700 nm such that:

$$0.2\sum_{305}^{700}\{L_\lambda t B(\lambda)\Delta\lambda\} \le 100\ J/(cm^2 \cdot sr) \quad for\ t \le 10^4 s$$

or

$$0.2\sum_{305}^{700}\{L_\lambda B(\lambda)\Delta\lambda\} \le 10^{-2}\ W/(cm^2 \cdot sr) \quad for\ t > 10^4 s$$

where B(λ) is the blue-light hazard function given in Appendix C Table C-8. [HS3101A]

Rationale: This is to prevent retinal photochemical injury from chronic exposure to visible light sources subtending an angle greater than or equal to 11 milliradians and with wavelengths between 305 and 700 nm. This is applicable to both internal and external vehicle light sources. The (TBD-006-003) limit is a cutoff value used to reduce the number of light sources that require testing to only those that are "brighter" and more likely to cause issues. Value is still being researched.

3.2.8.3.3 Thermal Injury from Infrared Radiation

3.2.8.3.3.1 Internal Infrared Radiation Limits

Window systems shall limit the level of internal infrared radiation exposure at wavelengths between 770 and 3000 nm to 10 mW/cm2 for exposure durations longer than 1000 seconds, and for exposure durations less than 1000 seconds such that:

$$0.2\sum_{770}^{3000}\{E_\lambda \Delta\lambda\} \le 1.8\, t^{-3/4} \quad W/cm^2$$

[HS3103]

Rationale: This is to protect the eye from thermal injury caused by overexposure to infrared radiation, including delayed effects to the lens (such as cataractogenesis.) This threshold limit value (TLV) applies to an environment with an ambient temperature of 37 °C, and can be increased by 0.8 mW/cm2 for every degree below 37 °C. Proper material selection *will aid in meeting requirements for both high transmittance of science windows and protection from non-ionizing radiation (this requirement).*

3.2.8.3.3.2 Light Sources Infrared Radiation Limits

Light sources in excess of (TBD-006-021) shall limit exposure to wavelengths between 770 and 3000 nm to 10 mW/cm2 for exposure durations longer than 1000 seconds, and for exposure durations less than 1000 second such that:

$$0.2\sum_{770}^{3000}\{E_{\lambda}\Delta\lambda\} \leq 1.8\ t^{-3/4} \quad W/cm^2$$

[HS3103A]

<u>Rationale:</u> This is to prevent thermal injury to the eye from overexposure to infrared radiation (wavelengths between 770 and 3000 nm). This included delayed effects to the lens such as cataractogenesis. This threshold limit value (TLV) applies to an environment with an ambient temperature of 37 degrees celsius, and can be increased by 0.8 mW/cm2 for every degree below 37 degrees celsius.

3.2.8.3.4 Ultraviolet Exposure for Unprotected Eye or Skin

3.2.8.3.4.1 Internal Spectral Irradiance Limits

Window systems shall limit the internal spectral irradiance at wavelengths between 180 and 400 nm weighted by the spectral effectiveness function Sλ (given in Appendix C Table C-9) to:

$$\sum_{180}^{400}\{E_{\lambda}S_{\lambda}t\Delta\lambda\} \leq 3\ mJ/cm^2 \quad in\ any\ 24\ hr\ \ period$$

A table of weighted spectral irradiances versus permissible exposure times is given in Appendix C Table C-10. [HS3104]

<u>Rationale:</u> This is to protect the eye and skin from injury caused by overexposure to ultraviolet radiation. A table of weighted spectral irradiances versus permissible exposure times is given in Appendix C Table C-10 for discrete irradiances for reference. These limits will be met by default when the limits set in Table C-9 are met. Proper material selection will aid in meeting requirements for both high transmittance of science windows and protection from non-ionizing radiation (this requirement)

3.2.8.3.4.2 Ultraviolet Light Source Limits

Light sources in excess of (TBD-006-005) shall limit exposure to wavelengths between 180 and 400 nm to:

$$\sum_{180}^{400}\{E_{\lambda}S_{\lambda}t\Delta\lambda\} \leq 3\ mJ/cm^2 \quad in\ any\ 24\ hr\ \ period$$

A table of weighted spectral irradiances versus permissible exposure times is given in Appendix C Table C-10. [HS3104A]

<u>Rationale:</u> This is to prevent injury to the eye or unprotected skin from ultraviolet light sources with wavelengths between 180 and 400 nm. Proper material selection will aid in meeting requirements for protection from non-ionizing radiation.

3.3 SAFETY

This section is not intended to be a comprehensive collection of requirements related to the safety.

Topics covered in this section include mechanical, electrical, fire and touch temperature hazards. Other safety topics are covered in their respective sections of the document.

3.3.1 GENERAL

3.3.1.1 Emergency Equipment Access

The Constellation Architecture shall provide access to emergency equipment within the time to address the emergency. [HS4022]

Rationale: *In the case of an emergency, access to emergency equipment must occur quickly, allowing the crew to take the proper actions to mitigate the situation. Each emergency may have a unique time requirement, and therefore a different constraint on access.*

3.3.2 MECHANICAL HAZARDS

3.3.2.1 Corners and Edges

Corners and edges to which the crew is expected to be exposed during normal operations shall be rounded as specified in Table D-1 in Appendix D. [HS4002]

Rationale: *Rounded corners and edges help to prevent personnel injury and damage to protective equipment (such as gloves and pressure suits) from sharp edges during normal operations, which may include suited operations.*

3.3.2.2 Corners and Edges - Maintenance

Corners and edges, except for equipment with functional sharp edges, to which the crew is only expected to be exposed during in-flight maintenance shall be rounded to at least 0.01 inches. [HS4003]

Rationale: *Rounded corners and edges help to prevent personnel injury and damage to protective equipment from sharp edges during maintenance. This does not apply to equipment with functional sharp edges, such as scissors, needles, and razor blades. This requirement is derived from the NASA-STD-3000 Manned System Integration Standards Document.*

3.3.2.3 Loose Equipment

Loose equipment, except for equipment with functional sharp edges, shall have corners and edges rounded as specified in Table 3.3-1. [HS4004]

Rationale: *Rounded corners and edges helps to prevent personnel injury and damage to protective equipment from sharp edges during normal operations. Equipment that can become loose and become a projectile must have more rounded corners and edges. This requirement is derived from the NASA-STD-3000 Manned System Integration Standards.*

Table 3.3-1 - Minimum Edge and Corner Radii for Loose Equipment

Equipment Mass		Minimum Edge radius mm (in)	Minimum Corner radius mm (in)
At Least kg (lb)	Less Than kg (lb)		
0.0 (0.0)	0.25 (0.5)	0.3 (0.01)	0.5 (0.02)
0.25 (0.5)	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 (33.0)	3.5 (0.14)	7.0 (0.3)
15.0 (33.0)	--	3.5 (0.14)	13.0 (0.5)

3.3.2.4 Burrs

Exposed surfaces shall be free of burrs. [HS4005]

Rationale: Removal of burrs can help to prevent personnel injury and damage to protective equipment from sharp edges during normal operations.

3.3.2.5 Sharp Items

Functionally sharp items shall be prevented from causing injury to the crew or damage to equipment when not in use. [HS4006]

Rationale: "Functionally sharp" items are those that, by their function, do not meet the requirement for exposed corners and edges (i.e. syringe, scissors, knife). These items must be prevented from causing harm when not in nominal use. Capping sharp items is one way of doing this.

3.3.2.6 Pinch Points

The vehicle shall prevent pinch points from injuring the crew. [HS4021]

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 providing guards to eliminate the potential to cause injury.

3.3.2.7 Equipment Restraints

The vehicle shall provide restraints for items that must be unstowed during any portion of the mission. [HS4007]

Rationale: Many pieces of flight equipment, such as portable computing device and photographic equipment, may be deployed during on-orbit or extra-orbital maneuvers. These must be restrained so that they do not harm the crew or other equipment.

3.3.3 ELECTRICAL HAZARDS

3.3.3.1 Electrical Hazard Potential

The Constellation Architecture shall protect the crew from electrical hazards per Tables 3.3-2 and 3.3-3. [HS4008]

Rationale: The values in the table represent the currents beyond which a person is not able to release his/her grip if holding onto an electrically energized surface, due to involuntary muscle contraction. The threshold current for let-go is dependent on the frequency and wave shape of the current.

Table 3.3-2 - - Electrical Hazard Potential

Voltage/Current	Hazard Level
1. Worst case credible failure results in exposure below threshold for shock:	none
a. Non-patient with internal voltages below 30 volts rms	
b. Current below maximum leakage current as defined in requirements HS4008B and HS4008C	
2. Worst case credible failure results in exposure exceeding threshold for shock and is below let-go current (Table 3.3-3)	Critical (two controls required)
3. Worst case credible failure results in exposure exceeding let-go current (Table 3.3-3)	Catastrophic (three controls required)

Table 3.3-3 - - Let-go Current

Frequency (Hz)	Threshold of Let–Go (milliamperes) (Based on 99.5 Percentile Rank of Adults) Maximum Total Peak Current (ac + dc components combined)
dc	40.0
15	8.5
2000	8.5
3000	13.5
4000	15.0
5000	16.5
6000	17.9
7000	19.4
8000	20.9
9000	22.5
10000	24.3
50000	24.3

3.3.3.2 Chassis Leakage Current - Non-patient Equipment

The Constellation Architecture shall limit the chassis leakage current for non-patient equipment to less than the values in Table 3.3-4. [HS4008B]

<u>Rationale:</u> *Chassis leakage current for non-patient equipment must not be great enough to shock the crew.*

Table 3.3-4 - - Chassis Leakage Current – Non-patient

Enclosure or Chassis Leakage Current			
Grounded		Double Insulated	
dc	ac ma	dc	ac ma
ma	rms	ma	rms
0.700	0.500	0.350	0.250

3.3.3.3 Chassis Leakage Current - Patient Equipment

The Constellation Architecture shall limit the chassis leakage current for patient care equipment to less than the values in Table 3.3-5. [HS4008C]

<u>Rationale:</u> *While some patient care equipment may produce current by function, the chassis leakage current must not be great enough to shock the crew.*

Table 3.3-5 - - Chassis Leakage Current - Patient

Patient Connection Leakage Current				
	Isolated (1)		Ordinary	
Patient	dc	ac ma	dc	ac ma
Interface	ma	rms	ma	rms
Invasive	0.014	0.010	Not Permitted	
Noninvasive	0.070 (1)	0.050 (1)	0.070	0.050
Enclosure or Chassis Leakage Current				
	Grounded		Double Insulated	
Patient	dc	ac ma	dc	ac ma
Interface	ma	rms	ma	rms
Noninvasive	0.140	0.100	0.070	0.050

Note:
(1) If equipment labeling indicates "isolated," the maximum current is 0.014 ma dc/0.010 ma rms.

3.3.4 TOUCH TEMPERATURES

3.3.4.1 Touch Temperature Limits

The Constellation Architecture shall limit the temperature of surfaces to which the bare skin of crew are exposed to the limits defined in Table 3.3-6. [HS4012]

Rationale: *High and low temperatures can cause discomfort and injury. They are especially troublesome in components of the user interface that the crew must touch to operate the vehicle. This also applies to a post-landing egress path of an Earth-entry vehicle, when the vehicle has experienced reentry heating. These temperature limits are derived from the NASA-STD-3000 Manned System Integration Standards and JSC Memo MA2-95-048, Thermal Limits for Intravehicular Activity (IVA) Touch Temperatures.*

Table 3.3-6 - Touch Temperature Limits for Bare Skin

Design Limit	Temperature	Material Adjusted Temperature
Maximum, Incidental or Momentary Contact	48.9 °C (120 °F)	TmPT =Maximum Permissible Material Temperature TmPT = YI [$(kpc)^{-1/2}$ + 31.5] + 41 where; YI = antilog [YII (a1) + log YIII]

Maximum, Continuous Contact (greater than 10 seconds)	45 °C (113 °F)	
Minimum	3.9 °C (39 °F)	

3.3.5 FIRE PROTECTION

3.3.5.1 Fire Suppression Portability

The vehicle shall provide a portable fire suppression system. [HS4019]

Rationale: The crew must have portable fire-fighting capability, even if a fixed fire-fighting system is provided.

3.4 ARCHITECTURE

This section contains requirements for the overall layout of the vehicle crew compartment. Specific topics include translation paths, mobility aids, restraints, hatches, windows and lighting.

3.4.1 CONFIGURATION

3.4.1.1 Layout Interference

The vehicle should separate functional areas whose functions would detrimentally interfere with each other. [HS5001]

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

3.4.1.2 Layout Sequential Operations

The vehicle should co-locate functional areas in which sequential operations are performed. [HS5002]

Rationale: *Co-location of related, sequential functional work areas can reduce transit time, communication errors, and operational delays. This consideration may seem to be met simply because of a vehicle's small size, but every effort should be made to group functions and capabilities supporting a task in as efficient a manner as possible to reduce crew workload. For example, food stowage and food preparation areas should be located near one another, to minimize the time required to retrieve food for meals.*

3.4.1.3 Workstation Visual Demarcations

The vehicle shall provide visual demarcations for adjacent workstations. [HS5042]

Rationale: *Visual demarcations are needed to ensure that the crew is visually notified where adjacent workstations begin, to prevent inadvertent use of other workstation elements. Examples are physical indentation in the metal, color coding and outlining.*

3.4.1.4 Orientation

Vehicle workstations shall provide all user-interface elements with the same orientation in roll as the sagittal plane of the restrained operator's head. [HS5003]

Rationale: *Maintaining a consistent orientation of workstation 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 should be made in design to minimize crewmember repositioning required to efficiently perform a task. This requirement is meant to ensure that all equipment at a workstation is aligned with the crewmember's head, even if the head is turned, so that an operating crewmember must only adjust their body orientation slightly in pitch and yaw at a workstation, but does not need to adjust their body orientation in roll.*

3.4.1.5 Location Coding

The vehicle shall use a standard location coding system to provide a unique identifier for each predefined location within the vehicle. [HS7009]

Rationale: Location coding provides a clear method of referring to different locations within the vehicle, and will serve as a communication and situational awareness 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 48 inches (122 cm) from the top of the surface (H indicates 8 alphabetic increments of 6 inches (15.2 cm) from the top).

3.4.2 TRANSLATION PATHS

3.4.2.1 Ingress, Egress, and Escape

The vehicle shall provide translation paths for ingress, egress and escape of pressurized-suited crewmembers. [HS5004]

Rationale: Pressurized-suited crewmembers must be able to get in and out of the vehicle easily and quickly.

3.4.2.2 Internal

The vehicle shall provide translation paths for the crew to conduct IVA operations. [HS5005]

Rationale: Translation paths are needed to support the safe and efficient movement of the crew throughout the vehicle. Translation paths around ISS eating stations have disrupted crew rest and relaxation required during meals.

3.4.3 RESTRAINTS AND MOBILITY AIDS

3.4.3.1 General

Restraints and mobility aids should be standardized throughout the vehicle. [HS5006]

Rationale: Standardization of restraints and mobility aids will reduce learning and recognition times, which is especially important in emergencies.

3.4.3.2 IVA Mobility Aids

The vehicle shall provide mobility aids for the crew to conduct IVA operations. [HS5007]

Rationale: Mobility aids, such as hand and foot restraints, allow crewmembers to efficiently move from one location to another in 0 g, 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. Without predefined available mobility aids, personnel will use available equipment that may be damaged from induced loads.

3.4.3.3 Workstations

The vehicle shall provide restraints to allow crewmembers to perform 2-handed operations at a workstation in 0g. [HS5008]

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 will float or move 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 must not require handholds to maintain position at a workstation, but may require restraints such as foot loops, straps, or harnesses.*

3.4.3.4 Ingress, Egress, and Escape

The vehicle shall provide mobility aids for ingress, egress, and escape of pressurized-suited crewmembers. [HS5009]

Rationale: *Because of the limited maneuverability of a pressurized-suited crewmember, mobility aids are required to allow crewmembers to safely and efficiently ingress and egress the vehicle.*

3.4.3.5 Crew Extraction

The Constellation Architecture shall provide a translation path for assisted ingress and egress of an incapacitated pressurized-suited crewmember. [HS5010]

Rationale: *Incapacitated pressurized-suited crewmembers may be unable to egress the vehicle on their own, and may also be in a constrained position that requires assisted extraction. Long-duration Russian and United States missions have shown that muscles atrophy and bones lose calcium in microgravity. Also, the heart adjusts to gravity-free pressures. On return to earth and rapid onset of gravity, even healthy humans temporarily need assistance for some mobility tasks.*

3.4.3.6 High g Environment

The Constellation Architecture shall prevent flail injury to restrained crewmembers. [HS5012]

Rationale: *During launch, abort and entry, there is potential for flail injury to the limbs if there is not proper restraint. Features such as harnesses, form-fitting seats, and tethers help maintain the proper position of the crewmember and prevent flailing. In addition, the design of the suit may contribute to reducing flail injury to the crew.*

3.4.3.7 Commonly Distinguishable

IVA handrails should be colored International Safety Yellow (TBR-006-037). [HS5052]

Rationale: *During emergencies, crews need to be able to quickly discern mobility aids from the surounding structures. Visual cues such as color coding may aid in this function. Commonality among visual cues is important so that crews and easily distinguish intended mobility aids from non-mobility aids that may be damaged by the application of crew-induced loads.*

3.4.4 HATCHES

3.4.4.1 Operation

3.4.4.1.1 Nominal

3.4.4.1.1.1 Inside and Outside

Vehicle hatches shall be operable from both the inside and outside. [HS5013]

Rationale: *Hatch operation includes unlatching/opening or closing/latching the hatch. This requirement addresses both nominal and contingency operations, including isolation of the vehicle from other vehicles in an emergency (e.g. depress, fire, toxic spill). The side hatch will be accessed from the inside during EVA, pad egress, and post-landing egress, and accessed from the outside in the case where docking fails and access to the vehicle must occur through the side hatch via EVA. The docking hatch will be accessed from the CEV side after docking with the LSAM/ISS, and from the LSAM/ISS side upon return.*

3.4.4.1.1.2 Operable in 60 Seconds

Vehicle hatches shall be operable in no more than 60 seconds. [HS5043]

Rationale: *Hatch operation includes unlatching/opening or closing/latching the hatch. Excessively long operating times can delay crews on both sides of a hatch. Sixty seconds is based on engineering judgement related to easily operable hatch design without complicating hatch design. This duration does not include pressure equalization.*

3.4.4.1.1.3 Without Tools

Vehicle hatches shall be operable without the use of tools. [HS5044]

Rationale: *Hatch operation includes unlatching/opening or closing/latching the hatch. Lost or damaged tools will prevent the hatches from being opened or closed, which may result in loss of crew or loss of mission. The use of Personal Protective Equipment (PPE) to protect ground personnel from temperature extremes after vehicle reentry are not considered tools and are not prohibited by this requirement.*

3.4.4.1.1.4 Suited

Vehicle hatches shall be operable by a single pressurized-suited crewmember. [HS5045]

Rationale: *Based on experience, opening a hatch by a pressurized-suited crewmember is more difficult than by an unsuited crewmember or an unpressurized-suited crewmember, due to reduced reach, mobility and limited manual dexterity due to gloved hands and the pressurized suit.*

3.4.4.1.1.5 Unlatching

Vehicle hatches shall require 2 distinct and sequential operations to unlatch. [HS5046]

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.*

3.4.4.1.2 Pressure Equalization

3.4.4.1.2.1 Inside and Outside

The vehicle shall provide manual pressure equalization from both the inside and outside. [HS5014]

Rationale: *Air pressure must 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 will enable hatch opening regardless of vehicle status.*

3.4.4.1.2.2 Suited

The vehicle shall allow manual pressure equalization by a pressurized-suited crewmember. [HS5048]

Rationale: *Based on experience, manual operations performed by pressurized-suited crewmembers are more difficult due to reduced reach, mobility, and limited manual dexterity due to gloved hands and the pressurized suit. In some vehicle failure scenarios, non-manual methods for pressure equalization may fail. Manual pressure equalization will enable hatch opening regardless of vehicle status.*

3.4.4.2 Indications

3.4.4.2.1 Status

3.4.4.2.1.1 Latch Position

The vehicle shall provide latch position status from the inside and outside of each hatch. [HS5049]

Rationale: *Indication of latch status on both sides of the hatch will allow both ground personnel (launch pad) and flight crew to verify that each hatch is latched. In combination with hatch closure status, this indicates proper security of the hatch.*

3.4.4.2.1.2 Hatch Closure

The vehicle shall provide hatch closure indication from the inside and outside of each hatch. [HS5016]

Rationale: *Indication of hatch closure status on both sides of the hatch will allow both ground personnel (launch pad) and flight crew to verify that each hatch is closed. In combination with latch position status, this indicates proper security of the hatch. Hatch closure implies that the hatch is in proper position to be latched.*

3.4.4.2.1.3 Pressure Difference

The vehicle shall provide direct pressure difference measurement on the inside and outside of each hatch. [HS5050]

Rationale: *Direct pressure difference measurement on both sides of the hatch will allow both ground personnel and flight crew to see the changes in pressure across the hatch and to know when the pressure difference is low enough to safely open the hatch. This function would be used as-needed, and pressure difference indication is not required at all times. However, the pressure difference indication must not require ground personnel or flight crew to call up a vehicle display.*

3.4.4.2.1.4 Visual Observation

The vehicle shall provide direct visual observation of the opposite side of the hatch. [HS5017]

Rationale: *Direct visual observation of what is located on the outside of the hatch allows the flight crew to determine the conditions or obstructions (such as the presence of fire or debris) on the other side of the hatch.*

3.4.5 WINDOWS

3.4.5.1 Optical Characteristics

Vehicle windows shall have the optical characteristics specified in JSC-63307 "Optical Design and Verification Criteria for Windows in Human Space Flight Applications". [HS5019]

Rationale: *The windows must be of sufficient optical performance so that they do not degrade visual acuity and performance. JSC 63307 provides optical quality specifications for different types of windows according to their associated tasks. Reference (i) "International Space Station Cupola Scratch Pane Window Optical Test Results", ATR-2003(7828)-1, January 17, 2003 and (ii) the Scientific and Technical Information Center Vehicle Integration and Test Office Window Testing report available at http://stic.jsc.nasa.gov/eresources/Imagery/index.html. To permit use of telephoto camera and high-definition video equipment, the windows must be of sufficient optical performance so that images retrieved will not be significantly degraded and distorted.*

3.4.5.2 Piloting Tasks

The vehicle shall provide windows for direct viewing for piloting tasks. [HS5021]

Rationale: *Because of the criticality of piloting tasks to the success of the mission and safety of the crew, the most reliable method of maintaining external observation is needed. Windows are reliable and familiar to pilots, and do not have many of the failure modes associated with cameras and display systems.*

3.4.5.3 External Observation

The vehicle shall provide a window for external observation. [HS5022]

Rationale: *Direct visual observation of the Earth, Moon and stars is needed for crew recreation and psychological health and may be used for science, navigation and inspection. This may not need to be a separate window; this requirement may be met with the use of an existing window.*

3.4.5.4 Covers and Shades without Tools

Vehicle window covers and shades that are designed to be removed or replaced during flight shall be removable and replaceable without the use of tools. [HS5051]

Rationale: *Where covers and shades are used, their removal and replacement must not be a burden to the crew, requiring the location and use of tools.*

3.4.5.5 Covers and Shades in 60 seconds

Vehicle window covers and shades that are designed to be removed or replaced during flight shall be removable and replaceable in less than 60 seconds. [HS5027]

Rationale: *Where window covers and shades are used, their removal and replacement must not be a time burden to the crew.*

3.4.5.6 Obstruction

The vehicle should define keep out zones to prevent the obstruction of windows' operational fields of view by any fixed equipment according to guidelines provided in Appendix M (TBR-006-068) [HS5030]

<u>Rationale:</u> Fixed equipment, such as window instrumentation, hardware, or a condensation prevention system, that would obscure the field of view from the nominal crew position for window viewing, may interfere with piloting tasks and photography tasks. Transparent, conductive coatings are readily available for use in electro-thermal condensation prevention systems in lieu of wires that would be visible in the field of view (e.g. rear window defoggers on automobiles). These coatings may in some cases also serve as an antireflective coating.

3.4.5.7 Internal Darkening

The vehicle shall provide an opaque shade, shutter, or internal protective cover for each window that prevents external light from entering the crew compartment in order to reduce the interior light level to 2 lux at 0.5 m (20 in) from each window. [HS5031]

<u>Rationale:</u> External illumination interferes with crew sleep and can interfere with onboard photography and videography. Covers block external illumination from entering the habitable compartments through windows.

3.4.5.8 Finishes

Areas within a 0.5 m (20 in) proximity to windows both internally and externally (where viewable from the inside) should have a flat, black finish or coating with reflectance less than 1% over a wavelength range of 400 to 800 nm, in order to reduce reflections and stray light. [HS5032]

<u>Rationale:</u> Many tasks require a clear viewing through the windows. Spurious reflections are reduced when a flat black finish is used on the window structure, around the window, on interior surfaces behind the window from the point of view of the observer, and especially on structure visible between the panes.

3.4.6 LIGHTING

3.4.6.1 Interior

3.4.6.1.1 General

The vehicle shall provide a minimum of 500 lux for general internal lighting. [HS5034]

<u>Rationale:</u> 500 lux is the light level required in the vehicle so that the crew can perform tasks without frequently requiring dedicated task lighting. The Illuminating Engineering Society of North America (IESNA) states in the ninth edition of the IESNA Lighting Handbook page 10-13 and 10-15 that illumination at the 500 lux level is defined to be for "performance of visual tasks of high contrast and small size or low contrast and large size". This meets the requirements of all the tasks in HSIR Table 3.4-1. Examples include reading small text (6 point), examining photographs of moderate detail and minor medical care. Task lighting may be used where general illumination is reduced due to temporary blockage by equipment or stowage.

3.4.6.1.2 Task

The vehicle shall provide the levels of light specified in Table 3.4-1, "Minimum Lighting Levels by Task" through a combination of general and task lighting. [HS5035]

Rationale: A wide range of crew tasks is expected to be performed within the vehicle. The lighting levels will vary dependant upon the task being performed. A single type of lighting at a single illumination level will be insufficient to support all tasks, therefore both general and task illumination will be required.

Table 3.4-1 - Minimum Lighting Level by Task

Task	Minimum Illumination (lux)	Measurement Location
Invasive wound care (cleaning/suturing)	500	At treatment surface (mucosa or skin)
Reading	350	On the page to be read
Handwriting/tabulating – ink on white paper	320	On the paper
Fine maintenance and repair work		On the affected component surface
Food preparation	300	On food preparation surfaces
Dining	250	On intended dining surfaces
Grooming		On the face located 50 cm. above center of mirror
Non-invasive wound care		On the wound
Exercise		On the exercise equipment
Video conferencing		On the face(s)
Gross Maintenance & housekeeping		On surfaces involved
Mechanical assembly		On the components involved
Manual controls	200	On the visible control surfaces
Panel – dark legend on light background		On the panel surface
Waste management	150	On the seat of the waste collection system
Translation	110	At all visible surfaces within the habitable volume
Panel – light legend on dark background	50	On the panel surface
Emergency equipment shutdown	30	On controls
Night lighting	20	On protruding surfaces
Emergency egress	10	On protruding surfaces

3.4.6.1.3 General Light Adjustability

Vehicle general lights shall be adjustable (dimmable) from their minimum output level (equal to less than 5% of maximum luminance) to their maximum luminance. [HS5034B]

Rationale: General lighting must be adjustable to permit the crew to use out-of-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.

3.4.6.2 Controls

3.4.6.2.1 Central

Controls for general lighting within each interior habitable volume shall be co-located within that volume. [HS5039]

Rationale: A single location for the control of general lighting, including power and dimming, allows interior light levels to be adjusted efficiently by a single crewmember.

3.4.6.2.2 Local

The vehicle shall provide workstation lighting control to a crewmember who is restrained at the workstation. [HS5040]

Rationale: Individual tasks or crewmembers may require or desire higher or lower lighting levels than that provided for other tasks or crewmembers.

3.4.6.2.3 Restrained

The vehicle shall provide means for a crewmember restrained at the workstation to adjust the position of the task light(s) for those workstations requiring repositionable workstation task lighting. [HS5041]

Rationale: Adjusting the position of a workstation light may be required during operations. It would create a hazard if a crewmember were required to leave the workstation during critical periods such as ascent, rendezvous, or entry.

3.5 CREW FUNCTIONS

The following section discusses the design and layout requirements of facilities for specific crew functions within the vehicle.

3.5.1 FOOD PREPARATION

3.5.1.1 Cross-Contamination

3.5.1.1.1 Cross-Contamination Prevention

The vehicle should prevent cross-contamination between food preparation and personal hygiene areas, and between food preparation and body waste management areas. [HS6001]

Rationale: This requirement helps protect crew health, by limiting the transfer of microorganisms to the food preparation area.

3.5.1.1.2 Cross-Contamination Separation

The distance between food preparation and body waste management areas should be as large as possible. [HS6002]

Rationale: This requirement is designed to prevent interference of body waste management functions with food preparation. Shuttle and ISS designs both put the waste management facilities unnecessarily close to the food preparation areas. It is a design goal, because the other constraints on the layout of the spacecraft interior may preclude meeting any specific separation between the food preparation area and, for example, the body waste management area.

3.5.1.2 Preparation

3.5.1.2.1 Heating

The vehicle shall heat food and drinks to between 68°C (155 °F) and 79°C (175 °F). [HS6003]

Rationale: Heating is required for subjective quality of food. Maintaining the temperature of rehydrated food above 68°C (155 °F) helps prevent microbial growth. Foods heated to above 79°C (175 °F) could cause heat-related injury to crewmembers. The vehicle should provide the ability to heat non-rehydrated foods.

3.5.1.2.2 Rehydration

The vehicle shall allow the crew to rehydrate food and drinks with potable water. [HS6004]

Rationale: Many foods must be rehydrated prior to consumption because (i) the water content of food is an important component of daily water intake, and (ii) people are used to the taste and texture of hydrated foods. Some foods must be rehydrated with hot water to ensure activation of certain chemical processes.

3.5.1.2.3 In-Flight Food Preparation Time

While in-flight, the vehicle should allow the crew to prepare each meal for all crewmembers within a single 30-minute period. [HS6005]

Rationale: 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. This 30 minute period is based on a one hour timelined meal which includes 5 minutes for unstowing, 25 minutes for food preparation, 20 minutes for eating, 3 minutes for wiping and cleaning, 2 minutes for trash stowage and 5 minutes for re-stow of meal related items. The intent of this requirement is not to preclude the preparation of meals that may take longer, if planned, but to provide vehicle capability for all crewmembers to eat a hot meal together within a scheduled 1 hour meal time.

3.5.1.2.4 Lunar Surface Food Preparation Time

While on the lunar surface, the vehicle shall allow the crew to prepare each meal for 4 crewmembers within a single 30 minute period. [HS6102]

Rationale: 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. This 30 minute period is based on a one hour timelined meal which includes 5 minutes for unstowing, 25 *minutes for food preparation, 20 minutes for eating, 3 minutes for wiping and cleaning, 2 minutes for trash stowage and 5 minutes for re-stow of meal related items. The intent of this requirement is not to preclude the preparation of meals that may take longer, if planned, but to provide vehicle capability for all crewmembers to eat a hot meal together within a scheduled 1 hour meal time.*

3.5.1.3 Food System

3.5.1.3.1 Food System

The Constellation Architecture shall provide a food system with a diet including the nutrient composition per Table 3.5-1 (TBR-006-021). [HS6059]

Rationale: A balanced diet is required to optimize crewmember health and performance. The values identified in Table 3.5-1 Nutritional Composition Breakdown are derived from the Nutrition requirements, Standards, and Operating Bands for Exploration Missions.

Table 3.5-1 - Nutrition Composition Breakdown Table (TBR-006-021)

Nutrients	Daily Dietary Intake
Protein	0.8 g/kg And ≤ 35% of the total daily energy intake And 2/3 of the amount in the form of animal protein and 1/3 in the form of vegetable protein
Carbohydrate	50–55% of the total daily energy intake
Fat	25–35% of the total daily energy intake
n-6 Fatty Acids	14 g
n-3 Fatty Acids	1.1 - 1.6 g
Saturated fat	As low as possible
Trans fatty acids	As low as possible
Cholesterol	As low as possible
Fiber	10–14 grams/4187 kJ
Fluid	1–1.5 mL/4187 kJ And ≥ 2000 mL
Vitamin A	700–900 μg
Vitamin D	25 μg
Vitamin K	Women: 90 μg Men: 120 μg
Vitamin E	15 mg
Vitamin C	90 mg
Vitamin B_{12}	2.4 μg
Vitamin B_6	1.7 mg
Thiamin	Women: 1.1 μmol Men: 1.2 μmol
Riboflavin	1.3 mg

Folate	400 µg
Niacin	16 mg NE
Biotin	30 µg
Pantothenic Acid	30 mg
Calcium	1200 - 2000 mg
Phosphorus	700 mg And ≤ 1.5 x calcium intake
Magnesium	Women: 320 mg Men: 420 mg And ≤ 350 mg from supplements only
Sodium	1500 - 2300 mg
Potassium	4.7 g
Iron	8 - 10 mg
Copper	0.5 - 9 mg
Manganese	Women: 1.8 mg Men: 2.3 mg
Fluoride	Women: 3 mg Men: 4 mg
Zinc	11 mg
Selenium	55 - 400 µg
Iodine	150 µg
Chromium	35 µg

3.5.1.3.2 Metabolic Intake

The Constellation Architecture shall provide each crewmember with an average of 12,707 kJ (3035 kilo-calories) per day. [HS6060]

Rationale: The estimated energy requirements (EER) for space missions is based on total energy expenditure (TEE), using an activity factor of 1.25 (active) along with the individual's age, body mass (kg), and height (m) in the following calculations: EER for men 19 y and older EER = 622 – 9.53 x Age [y] + 1.25 x (15.9 x Mass [kg] + 539.6 x Ht [m]) and EER for women 19 y and older EER = 354 – 6.91 x Age [y] + 1.25 x (9.36 x Mass [kg] + 726 x Ht [m]). The value given in the requirement is based on the projected values for a mean male astronaut population in the year 2015 with a stature of 178.6 cm and a weight of 82.4 kg. The age used for these calculations is 45 years old. This requirement is derived from the Nutrition requirements, Standards, and Operating Bands for exploration missions.

3.5.1.4 EVA Operations

3.5.1.4.1 Nutrition for Suited Operations

The Constellation Architecture shall provide no less than an additional 837 kJ (200 kilocalories) per hour of EVA above nominal metabolic intake as defined in HS6060 for crewmembers performing EVA operations, similar in nutrient composition to the rest of the diet per Table 3.5-1 (TBR-006-021). [HS6062]

Rationale: Additional nutrients, including fluids, are necessary during suited operations as crewmember energy expenditure is greater during those activities. This requirement also supplies the crew with nutrition during extended contingency use of pressure suits. Nutritional requirements are derived from the Nutrition requirements, Standards, and Operating Bands for Exploration Missions document.

3.5.1.4.2 Water for Suited Operations

The Constellation Architecture shall provide an additional 240 mL (8 ounces) of potable water per hour above nominal potable water provision as defined in HS3025 for crewmembers performing EVA operations with durations greater than 4 hours, of which 950 mL (32 ounces) (TBR-006-038) are available for consumption in the pressurized suit. [HS6063]

Rationale: Potable water is necessary during suited operations to prevent dehydration due to perspiration and insensible water loss as well as to improve crew comfort. The additional 240 mL (8 ounces) is based upon measured respiratory and perspiratory losses during suited operations.

3.5.2 PERSONAL HYGIENE

3.5.2.1 Privacy

The vehicle shall provide visual privacy for personal hygiene. [HS6009]

Rationale: Certain hygiene functions require a degree of privacy, especially in a vehicle in which other crewmembers may be performing other functions simultaneously.

3.5.2.2 Stowage

The vehicle should provide readily accessible stowage for personal hygiene supplies. [HS6010]

Rationale: Personal hygiene supplies, such as tissues and towels, may need to be accessed rapidly.

3.5.2.3 Trash

The vehicle should provide readily accessible trash collection for disposable personal hygiene supplies. [HS6012]

Rationale: Crewmembers require readily accessible trash collection for disposable personal hygiene supplies to minimize crew exposure to the used items. Access to trash collection hardware or compartments should not require the use of any tools or reconfiguration of vehicle hardware.

3.5.2.4 Full Body Visual Privacy

The vehicle shall provide full body visual privacy for body waste management. [HS6027]

Rationale: In a small vehicle, provisions for privacy during waste management allow activities such as videoconferences to proceed uninterrupted.

3.5.2.5 Body Self-Inspection and Cleaning

The vehicle should provide a means and sufficient volume for crewmembers to perform bodily self-inspection and cleaning after urination and defecation. [HS6028]

Rationale: *In zero g, body waste can float. Therefore, after waste management, it is important for crewmembers to verify that they are clean.*

3.5.3 BODY WASTE MANAGEMENT

3.5.3.1 Vomitus

3.5.3.1.1 Collection and Containment

The vehicle shall provide for the collection and containment of vomiting events of 0.5 L each as indicated in Table 3.5-2. [HS6013]

Rationale: *Vomiting and its associated odor, mainly produced by the compound putrescene, may trigger a bystander nausea and vomiting reaction in adjacent crewmembers located in close proximity in an enclosed space. Space Adaptation Syndrome (SAS) occurs in up to 70% of first time fliers (30% of whom may experience vomiting) during the first 48-72 hours of microgravity. In addition, a possible water landing may cause crew members to succumb to sea sickness. The average number of vomiting episodes per crewmember will vary from 1 to 6 per day, over a 2- to 3- day period. Regurgitation of the entire stomach contents will result on average in 0.2 to 0.5 L of vomitus per event. Stowage and disposal should be adequate for a worst case number of involved crew, severity and duration of symptoms, as well as volume of gastrointestinal contents regurgitated. The total capacity of 4 L for CEV missions should accommodate 4 in flight events with a total volume of 2 L for the SAS portion of the mission and 4 events post flight with a total volume of 2 L for a possible water landing. The total capacity of 0.5 L per crewmember per mission for LSAM missions should accommodate 1 inflight event per crewmember to account for possible food-borne vomiting events.*

Table 3.5-2 - Vomitus Collection and Containment

Mission	Design-to Number of Vomiting Events Per Crew
CEV to or from ISS	8
CEV Lunar Mission	8
LSAM	1
Lunar Surface Habitat	TBD-006-053

3.5.3.2 Feces

3.5.3.2.1 Wipes

The vehicle shall provide for collection and containment of the following fecal matter and associated supplies: Consumable wipe materials. [HS6016]

Rationale: *Used consumable wipe materials must be collected and contained in a manner than minimizes possible escape of fecal contents into the habitable vehicle during microgravity operations, because of the high content of possibly pathogenic bacteria contained in the stool and because of the potential of injury to crewmembers and hardware that could result from such dissemination. The collection capacity accounts for the average healthy adult* *stool output/day. Historically, on Shuttle, a total of 20 wipes per crewmember per day were flown for waste management. The Shuttle wipes packages hold 40 wipes and have the following dimensions: 20.3cm x 10.9cm x 4.6cm (8.0" x 4.3" x 1.8").*

3.5.3.2.2 Feces, per Day

The vehicle shall provide for collection and containment of the following fecal matter and associated supplies: Collection of an average of 150 grams (by mass) and 150 mL (by volume) of fecal matter per crewmember per defecation at an average of two defecations per day. [HS6017]

Rationale: Fecal waste collection must be performed in a manner than minimizes possible escape of fecal contents into the habitable vehicle during microgravity operations, because of the high content of possibly pathogenic bacteria contained in the stool and because of the potential of injury to crewmembers and hardware that could result from such dissemination. The collection capacity accounts for the average healthy adult stool output/day. The number of defecations per day is individually variable ranging from two times per week to five times per day , with the assumed average of two times per day.

3.5.3.2.3 Feces, per Event

The vehicle shall provide for collection and containment of the following fecal matter and associated supplies: Collection of 500 grams (by mass) and 500 mL (by volume) of fecal matter per crewmember in a single event. [HS6020C]

Rationale: Fecal waste collection must be performed in a manner than minimizes possible escape of fecal contents into the habitable vehicle during microgravity operations, because of the high content of possibly pathogenic bacteria contained in the stool and because of the potential of injury to crewmembers and hardware that could result from such dissemination. The collection capacity accounts for the average healthy adult maximum output during a single event.

3.5.3.2.4 Diarrhea, per event

The vehicle shall provide for collection and containment of the following fecal matter and associated supplies: Collection of 2 L of diarrheal discharge in a single event [HS6020]

Rationale: Fecal waste collection must be performed in a manner than minimizes possible escape of fecal contents into the habitable vehicle during microgravity operations, because of the high content of possibly pathogenic bacteria contained in the stool and because of the potential of injury to crewmembers and hardware that could result from such dissemination. The fecal discharge due to gastrointestinal illness (diarrhea) occurs at an increased frequency and volume, but is also variable and unpredictable. The volume for a single discharge is to accommodate diarrhea caused by likely pathogens such as Rotavirus and Enterotoxigenic E coli. 2 Liters is based on evaluation of individuals afflicted with pathogenic diarrhea, as found in medical literature, based on most likely maximal discharge in afflicted individuals.

3.5.3.2.5 Diarrhea, per mission

The vehicle shall provide for collection and containment of the following fecal matter and associated supplies: Collection of 8 L of diarrheal discharge per crewmember per mission. [HS6018]

Rationale: Fecal waste collection must be performed in a manner than minimizes possible escape of fecal contents into the habitable vehicle during microgravity operations, because of the high content of possibly pathogenic bacteria contained in the stool and because of the potential of injury to crewmembers and hardware that could result from such dissemination. The fecal discharge due to gastrointestinal illness (diarrhea) occurs at an increased frequency but is also variable and unpredictable. The total collection volume is to accomodate diarrhea caused by likely pathogens such as Rotavirus and Enterotoxigenic E coli.

3.5.3.2.6 Diarrhea, events per crewmember

The vehicle shall provide for the collection and containment of a maximum of 16 diarrheal events per crewmember per mission, except on CEV ISS Transfer missions, during which it will provide collection and containment of up to 8 diarrheal events per crewmember per mission. [HS6020D]

Rationale: In order to properly accommodate diarrheal events, the number events must be specified. It is assumed that there is an average volume of 0.5 L per event.

3.5.3.3 Urine

3.5.3.3.1 Containment

The vehicle shall provide the following provisions for the collection and containment of urine: A crew interface that captures urine and controls splash. [HS6021]

Rationale: Urine output may be slightly greater or lower in various phases of the mission associated with g- transitions and fluid intake levels. The urinary collection system must be capable of collecting all of the crewmember's output in succession, with an average void varying from 100 to 500 mL. Rarely, a single void might be as much as 1 L, so the equipment should be able to accommodate this maximum. The rate of urinary delivery into the system from the body will vary by gender (greater for females because of lower urethral resistance) but averages 10 to 35 mL/s. Maximum flow-rate with abdominal straining in a female may be as high as 50 mL/s for a few seconds. The voided urine must be contained by the stowage and disposal hardware to prevent inadvertent discharge in the cabin that could result in injury to crewmember's mucous membranes or equipment.

3.5.3.3.2 Wipes

The vehicle shall provide the following provisions for the collection and containment of urine: Disposal of associated consumable wipe materials. [HS6022]

Rationale: Urine output may be slightly greater or lower in various phases of the mission associated with g- transitions and fluid intake levels. The urinary collection system must be capable of collecting all of the crewmember's output in succession, with an average void varying from 100 to 500 mL. Rarely, a single void might be as much as 1 L, so the equipment should be able to accommodate this maximum. The rate of urinary delivery into the system from the body will vary by gender (greater for females because of lower urethral resistance) but averages 10 to 35 mL/s. Maximum flow-rate with abdominal straining in a female may be as high as 50 mL/s for a few seconds. The voided urine must be contained by the stowage and disposal hardware to prevent inadvertent discharge in the cabin that could result in injury to crewmembers' mucous membranes or equipment. Historically, on Shuttle, a total of 20 wipes *per crewmember per day were flown for waste management. The Shuttle wipes packages hold 40 wipes and have the following dimensions: 20.3cm x 10.9cm x 4.6cm (8.0" x 4.3" x 1.8").*

3.5.3.3.3 Urine per Crewmember

The vehicle shall provide the following provisions for the collection and containment of urine: Collection of a maximum urine output volume of

$$V_U = 3 + 2t$$

liters per crewmember, where t is the mission length in days. [HS6023]

<u>Rationale:</u> *Urine output may be slightly greater or lower in various phases of the mission associated with g- transitions and fluid intake levels. The urinary collection system must be capable of collecting all of the crewmember's output in succession, with an average void varying from 100 to 500 mL. Rarely, a single void might be as much as 1 L, so the equipment should be able to accommodate this maximum. The rate of urinary delivery into the system from the body will vary by gender (greater for females because of lower urethral resistance) but averages 10 to 35 mL/s. Maximum flow-rate with abdominal straining in a female may be as high as 50 mL/s for a few seconds. The voided urine must be contained by the stowage and disposal hardware to prevent inadvertent discharge in the cabin that could result in injury to crewmember's mucous membranes or equipment.*

3.5.3.3.4 Urine per Hour

The vehicle shall provide the following provisions for the collection and containment of urine: Collection of 6 urinary discharges of 1 L each, per hour. [HS6024]

<u>Rationale:</u> *Urine output may be slightly greater or lower in various phases of the mission associated with g- transitions and fluid intake levels. The urinary collection system must be capable of collecting all of the crewmember's output in succession, with an average void varying from 100 to 500 mL. Rarely, a single void might be as much as 1 L, so the equipment should be able to accommodate this maximum. The rate of urinary delivery into the system from the body will vary by gender (greater for females because of lower urethral resistance) but averages 10 to 35 mL/s. Maximum flow-rate with abdominal straining in a female may be as high as 50 mL/s for a few seconds. The voided urine must be contained by the stowage and disposal hardware to prevent inadvertent discharge in the cabin that could result in injury to crewmember's mucous membranes or equipment.*

3.5.3.3.5 Urine per Day

The vehicle shall provide the following provisions for the collection and containment of urine: Collection of an average of 6 urinations per crewmember per day. [HS6025B]

<u>Rationale:</u> *The number of urinations per day is individually variable with the assumed average of six times per day. Urine output may be slightly greater or lower in various phases of the mission associated with g- transitions and fluid intake levels. The urinary collection system must be capable of collecting all of the crewmember's output in succession, with an average void varying from 100 to 500 mL. Rarely, a single void might be as much as 1 L, so the equipment should be able to accommodate this maximum. The rate of urinary delivery into the system from the body will vary by gender (greater for females because of lower urethral resistance) but*

averages 10 to 35 mL/s. Maximum flow-rate with abdominal straining in a female may be as high as 50 mL/s for a few seconds. The voided urine must be contained by the stowage and disposal hardware to prevent inadvertent discharge in the cabin that could result in injury to crewmember's mucous membranes or equipment.

3.5.3.3.6 Urine Rate

The vehicle shall provide the following provisions for the collection and containment of urine: Collection of urinary discharges of up to 1 L in a single micturition, at a maximum delivery of 0.4 L in 2 seconds. [HS6025]

Rationale: *Urine output may be slightly greater or lower in various phases of the mission associated with g- transitions and fluid intake levels. The urinary collection system must be capable of collecting all of the crewmember's output in succession, with an average void varying from 100 to 500 mL. Rarely, a single void might be as much as 1 L, so the equipment should be able to accommodate this maximum. The rate of urinary delivery into the system from the body will vary by gender (greater for females because of lower urethral resistance) but averages 10 to 35 mL/s. Maximum flow-rate with abdominal straining in a female may be as high as 50 mL/s for a few seconds. The required rate allows for urinary slug volume that could accumulate in case the crew member blocks airflow with their body. The voided urine must be contained by the stowage and disposal hardware to prevent inadvertent discharge in the cabin that could result in injury to crewmember's mucous membranes or equipment.*

3.5.3.4 Defecation and Urination

3.5.3.4.1 Simultaneous

The vehicle shall allow an unsuited crewmember to defecate and urinate simultaneously, without completely removing lower clothing. [HS6014]

Rationale: *This capability will ensure that there is no accidental discharge of one or both waste components into the habitable volume of the vehicle, as many individuals are incapable of relaxing the gastrointestinal control sphincter without relaxing the urinary voluntary control sphincter, and vice versa. To minimize impact to crew operations, waste elimination needs to be accomplished with minimal crew overhead, e.g. without completely removing clothing.*

3.5.3.5 Odor Control

3.5.3.5.1 Waste Management Equipment

The vehicle shall provide odor control for the waste management equipment. [HS6029]

Rationale: *Uncontrolled waste-associated odors can have an adverse affect on crew performance, and can exacerbate pre-existing symptoms of Space Motion Sickness.*

3.5.3.5.2 Auditory and Olfactory Privacy

The vehicle should provide auditory and olfactory privacy for body waste management. [HS6069]

Rationale: *In a small vehicle, provisions for privacy during waste management allow things like videoconferences to proceed uninterrupted.*

3.5.3.6 Stowage

3.5.3.6.1 Waste Management Stowage

The vehicle shall provide waste management supplies at a location that is accessible to the crewmember using the waste management station. [HS6030]

Rationale: *Waste management wipes must be accessible where they are needed, in or immediately adjacent to the waste management system within reach of the crewmember.*

3.5.3.7 Trash

3.5.3.7.1 Waste Management Trash

The vehicle should provide readily accessible trash collection, with odor control, for waste management items. [HS6031]

Rationale: *Waste management items which cannot be collected and contained with human waste must be disposed of immediately after use and within reach of the crewmember without egressing the waste management restraint system, and without the need to access closed compartments.*

3.5.4 EXERCISE

3.5.4.1 Availability

3.5.4.1.1 Exercise Availability

The Constellation Architecture shall allow aerobic and resistive exercise training for 30 continuous minutes each day per crewmember for missions greater than 8 days. [HS6032]

Rationale: *An exercise capability is not required on CEV missions to ISS or for missions with total durations of less than 8 days. Exercise is required on Lunar missions greater than 8 total days to maintain crew cardiovascular fitness (to aid in ambulation during g-transitions and to minimize fatigue), to maintain muscle mass and strength/endurance (to complete mission tasks such as EVA walk-back and contingency response capability) and for recovery from strenuous tasks, confined postures, and to rehabilitate minor muscle injuries. Per Apollo crew participating in the June 2006 Apollo Medical Summit (Houston, TX), exercise should be commenced as early as possible during the mission and continue throughout all mission phases. Exercise should start as early as possible during the mission but no later than flight day 4, until end of mission minus one day. Expected CO2, heat and water output can be found in Table E-2 in Appendix E Crewmember Metabolic Profile in the appendix.*

3.5.4.2 Operational Envelope

3.5.4.2.1 Exercise Operational Envelope

The vehicle shall provide 2.23m x 1.01m x 1.31m (7.3ft x 3.3ft x 4.3ft) (TBR-006-031) of operational envelope for completion of exercise during non-dynamic mission phases, when exercise is being conducted. [HS6035]

Rationale: *The operational envelope is the greatest volume required by a crewmember to use an exercise device (not the deployed volume of the device) and is derived utilizing the HSIR Critical Anthropometry Dimensions Table B-7 for maximum stature, standing and maximum sitting height while using a rower/cycle ergometer device (no arms overhead).*

3.5.4.3 Environmental Loads

3.5.4.3.1 Thermal Environment

The vehicle shall maintain the vehicle's thermal environment, as defined in HS3036 and HS3037, during crew induced thermal loading as defined in Table E-2 Crew Induced Metabolic Loads in Appendix E. [HS6036]

Rationale: Each crewmember can be expected to generate these heat loads during a mission. Further rationale is found in the table E-2 legend and its associated appendix E.

3.5.4.3.2 Oxygen

The vehicle shall provide O2 for crew consumption as defined in Table E-2 Crew Induced Metabolic Loads in Appendix E. [HS6073]

Rationale: Each crewmember can be expected to consume these O2 quantities during a mission. Further rationale is found in the table legend.

3.5.4.3.3 Carbon Dioxide

The vehicle shall maintain the vehicle's atmospheric gases, as defined in HS3005, during crew generated CO2 loading as defined in Table E-2 Crew Induced Metabolic Loads in Appendix E. [HS6037]

Rationale: Each crewmember can be expected to generate these CO2 loads during a mission. Further rationale is found in the Table E-2 legend.

3.5.4.3.4 Relative Humidity

The vehicle shall maintain the vehicle's relative humidity, as defined in HS3046, during crew generated water vapor loading as defined in Table E-2 Crew Induced Metabolic Loads in Appendix E. [HS6038]

Rationale: Each crewmember can be expected to generate these water vapor loads during a mission. Further rationale is found in the Table E-2 legend.

3.5.5 SPACE MEDICINE

3.5.5.1 Data and Communications

3.5.5.1.1 Private Voice

The vehicle shall provide two-way private voice communication with Mission Systems. [HS6075]

Rationale: Private voice communication will assure the exchange of medical information, therapeutic confidences, and psychological conferences between the crew and the medical operations support team as well as family conferences will remain private. This will include private post-landing communication between the flight surgeon and crew, as well as an EMS coordinator if necessary. The flight surgeon staffing the Surgeon console in the mission control center is responsible for providing flight crew medical information to the site EMS Coordinator and keep the Flight Control Team informed of pertinent information at all times. In order to provide this support, the flight surgeon needs to have a private voice communications capability with the crew and EMS Coordinator throughout the contingency, including the *medical situation, prior to landing and post-landing. Private voice communications are not required during Earth ascent and entry.*

3.5.5.1.2 Private Video

The vehicle shall provide private video capability with Mission Systems during all mission phases except ascent, entry, and post landing. [HS6076]

Rationale: Private video communication will assure the exchange of medical information, therapeutic confidences, and psychological conferences between the crew and the medical operations support team as well as family conferences will remain private. This does not imply a private location in the vehicle.

3.5.5.1.3 Communication Capabilities

The Constellation Architecture shall provide audio, text, and video uplink and downlink capabilities with a delivery delay of less than 4 hours (TBR-006-051). [HS6097]

Rationale: The behavioral health and performance countermeasures are necessary for successful adaptation to living and working in an isolated and confined environment, maintaining individual behavioral health and performance, and maintaining performance and functioning of the entire crew as a unit. To be effective, countermeasures must be available that are consistent with individual and team needs, mission duration, and crew duty periods. The audio, text, video and e-mail uplink and downlink capabilities will be used to uplink news (audio/video and written summaries), recreational audio and video materials as well as maintain contact with family, friends, and other individuals or organizations.

3.5.5.1.4 Personalized In-Flight Updates

The Constellation Architecture shall provide for in-flight updates of the personalized on-board databases. [HS6099]

Rationale: The behavioral health and performance countermeasures are necessary for successful adaptation to living and working in an isolated and confined environment, maintaining individual behavioral health and performance, and maintaining performance and functioning of the entire crew as a unit. To be effective, countermeasures must be available that are consistent with individual and team needs, mission duration, and crew duty periods. Periodic updates to the personalized on-board databases are necessary for the crewmember to aid in psychological adaptation by providing similar off-duty activities to those performed at home.

3.5.5.1.5 Biomedical Data

The vehicle shall collect biomedical data during suited operations. [HS6077]

Rationale: Biomedical data transmission to the ground mission control center will be required for suited operations, therefore the vehicle will need to collect biomedical data.

3.5.5.1.6 Biomedical Relay

The vehicle shall relay biomedical telemetry to Mission Systems during suited operations. [HS6078]

Rationale: Ground medical support during nominal and contingency EVA as well as during unrecoverable vehicle pressure loss is necessary to ensure the health and safety of the crewmember(s) and to provide appropriate information to the Flight Director. Supervision of the biomedical data will maximize crew resource management for the event and minimize risk for the crewmember(s).

3.5.5.1.7 Biomedical Display

The vehicle shall display biomedical data to the crew. [HS6079]

Rationale: The crew requires this capability of optimizing consumable use and to prevent operation outside of safe zone (examples: thermal and oxygen). The data displayed to the crew is to be real-time.

3.5.5.2 Vehicle Pressure

3.5.5.2.1 DCS Repressurization

The vehicle shall pressurize from vacuum to nominal vehicle pressure within 15 minutes. [HS6080]

Rationale: Decompression sickness (DCS) is a potential hazard of space flight and EVA. Rapid and appropriate intervention is required to optimize the outcome for the affected crewmember(s). The U.S. Navy Treatment Table 6 is the terrestrial standard for treating DCS, however the terrestrial standard will not be met because the expected risk of DCS is low and the resources required to support it would be prohibitive. Instead, treatment vessels for the delivery of hyperbaric oxygen may include pressure suits, airlocks, and vehicle habitable volumes, which may be used independently or in combination to acheive specified pressures. The treatment plan will also include specific diagnostic and therapeutic procedures including guidance for decisions on return contingencies and plans for terrestrial response after deorbit of the crewmember(s) with DCS. If treated within 20 minutes, lower pressures may resolve DCS symptoms. The requirement is therefore to have pressure available within 15 minutes for a margin of safety. Beyond 20 minutes, higher pressures are required to address DCS symptoms.

3.5.5.2.2 DCS Overpressurization

The Constellation Architecture shall provide a pressure of 156.5 kPa (22.7 psi) (1174 mmHg) (TBR-006-015) to a DCS-affected crewmember, within 2 hours of a DCS event, for a minimum of 6 hours (TBR-006-016). [HS6081]

Rationale: Decompression sickness (DCS) is a potential hazard of space flight and EVA, due to changes in the operational pressure environment. Following initial treatment of DCS symptoms with hyperoxic pressure, it is usually necessary to provide follow-on treatment with higher levels of pressure for treatment of unresolved or recurrent DCS symptoms, or prevention of recurrent symptoms. In order to prevent progression of DCS symptoms or the development of DCS-induced deficits or permanent sequelae, in cases of unresolved or recurrent DCS symptoms, it is necessary to provide prompt pressure to the crewmember, above that of the starting vehicular pressure. Rapid and appropriate intervention is required to optimize the outcome for the affected crewmember(s). The U.S. Navy Treatment Table 6 in a hyperbaric treatment facility is the terrestrial standard for treating most forms of DCS, however the terrestrial standard will not be achievable, nor required, because the resources required to *support it would be prohibitive, and the expected outcomes from sub-terrestrial standard therapy is likely to be adequate for "altitude-induced" DCS symptoms. Instead, treatment vessels for the delivery of hyperbaric oxygen may include pressure suits, airlocks, and vehicle habitable volumes, which may be used independently or in combination to achieve specified pressures. The pressure of 156.5 kPa (22.7 psi) (1174 mmHg) (TBR-006-015) is chosen to match current DCS treament capability on ISS consisting of 101.4 kPa (14.7 psi) (760 mmHg) vehicular + 55.2 kPa (8.0 psi) (413 mmHg) - 57.2 kPa (8.3 psi) (429 mmHg) EMU suit pressure when operating the Bends Treatment Apparatus). The DCS treatment pressure may be achieved by a combination of pressure vessels to include maximal vehicular or airlock pressure + maximal suit pressure. If the assumption of maximal operating lunar pressure is 72.4 kPa (10.5 psi) (543 mmHg) + suit is 56.5 kPa (8.2 psi) (424 mmHg), then the airlock or portable chamber would need to provide an additional 27.6 kPa (4 psi) (207 mmHg) of pressure to meet this requirement. The treatment plan will also include specific diagnostic and therapeutic procedures including guidance for decisions on return contingencies and plans for terrestrial response return of the crewmember(s) with DCS, if return is required based on incomplete response to treatment. Late onset or severe DCS requires higher pressures to treat, but should still be administered as quickly as possible following the onset of symptoms for maximum effectiveness. For the scenario when the vehicle cannot maintain pressure such as the uncontrolled cabin depressurization contingency (120-hour), then 156.5 kPa (22.7 psi) (1174 mmHg) DCS treatment pressure will not be obtainable. In this case the architecture must provide a minimum of 55.2 kPa (8 psi) (413 mmHg) greater than ambient pressure for a minimum of 6 hours.*

3.5.5.2.3 DCS Event Pressure

The Constellation Architecture shall provide a minimum of 55.2 kPa (8 psi) (413 mmHg) (TBR-006-053) to a DCS-affected crewmember, within 20 minutes of a DCS event. [HS6100]

Rationale: *Decompression sickness (DCS) is a potential hazard of space flight and EVA, due to changes in the operational pressure environment. If treatment for DCS is instituted within 20 minutes of onset of symptoms, then the outcome of therapy has a higher probability of success, and will likely require less magnitude and duration of hyperbaric oxygen therapy. The rapid response DCS treatment pressure of 55.2 kPa (8 psi) (413 mmHg) is used because it is the lowest nominal vehicle operating pressure anticipated. The U.S. Navy Treatment Table 6 in a hyperbaric treatment facility is the terrestrial standard for treating most forms of DCS, however the terrestrial standard will not be achievable, nor required, because the resources required to support it would be prohibitive, and the expected outcomes from sub-terrestrial standard therapy is likely to be adequate for "altitude-induced" DCS symptoms. Instead of a multi-place hyperbaric chamber, treatment vessels for the delivery of space DCS treatment may include pressure suits, airlocks, and vehicle habitable volumes, which may be used independently or in combination to achieve specified pressures and enriched/hyperbaric oxygen treatment. The treatment plan will also include specific diagnostic and therapeutic procedures based on the severity of DCS symptoms observed, and may include fluids (intravenous or oral), anti-inflammatory medications, etc.*

3.5.5.2.4 Denitrogenation

The Constellation Architecture shall maintain the pressure and gaseous composition for denitrogenation of the crew per Table (TBD-006-008). [HS6091]

Rationale: Standardization of nitrogen washout (pre-breathe) will minimize the risk of decompression sickness during reduced pressure operations.

3.5.5.3 Orthostatic Protection

3.5.5.3.1 Orthostatic Protection

The vehicle shall provide crewmember orthostatic protection for return into a 1g environment. [HS6082]

Rationale: Orthostatic protection is needed to minimize operational impacts. Operational impacts can include loss of consciousness, inability to operate controls and inability to egress vehicle without assistance and thus could jeapordize the success of the re-entry and landing of the vehicle and the safety of the crewmembers. Methods that have been successfully used to prevent orthostasis include fluid/salt loading regimens to maintain hydration, constrictive leg garments to prevent blood pooling, active cooling to maintain crew comfort, and recumbent crewmember seating to improve cerebral blood flow in 1g. Furthermore, research studies of pharmacologic measures are also promising.

3.5.5.4 Interfaces

3.5.5.4.1 Interfaces

The vehicle shall provide interfaces for potable water, pressurized oxygen, power, and data transfer used to support medical care for an ill or injured crew member, as defined by the Interface Requirements Document for Portable Equipment Payloads and Cargo (CxP 70035). [HS6095]

Rationale: The interfaces for a variety of urgent care medical equipment, including information system interfaces, will allow crew members to use the medical equipment to properly support an ill or injured crewmember, or to allow medical information to be relayed to flight surgeons on Earth in support of medical operations implemented by crew members. The specific equipment, number of equipment components, and required number of interfaces, are defined in the Constellation Medical Equipment IRD (Interface Requirements Document for Portable Equipment Payloads and Cargo CxP 70035).

3.5.5.5 Medical Area and Capability

3.5.5.5.1 Medical Care Provider Access

The vehicle shall provide a designated area with the following medical capabilities: Medical care provider access to ill/injured crewmember [HS6083]

Rationale: The medical care provider may need to complete tasks in close proximity to the ill/injured crewmember. This includes tasks such as providing positive pressure ventilation. This applies to all mission phases except Earth launch and lunar descent

3.5.5.5.2 Patient Electrical Isolation

The vehicle shall provide a designated area with the following medical capabilities: Patient electrical isolation. [HS6084]

Rationale: To protect both the avionics of the vehicle and other crewmembers from inadvertent electrical shock, the patient will need to be electrically isolated from the vehicle in the event defibrillation is required.

3.5.5.5.3 Access to Medical Equipment

The vehicle shall provide a designated area with the following medical capabilities: Access for medical equipment to patient interfaces. [HS6085]

Rationale: The medical provider, or caregiver, must be able to attach medical equipment appropriately to the ill/injured crewmember within the designated area. The term "patient interface" is used to denote any part of the patient which must come in contact with the medical equipment. For example, there must be enough volume in the designated area for a pulse oximeter probe to be attached to a patient's finger to obtain pulse oximetry data.

3.5.5.5.4 Access to Deployed Medical Kits

The vehicle shall provide a designated area with the following medical capabilities: Access to deployed medical kits within reach of medical care provider. [HS6086]

Rationale: In order for the medical care provider to effectively attend to an ill/injured crewmember, the provider must be able to reach the equipment and supplies in the deployed medical kits. This requirement is to ensure the provider can obtain equipment and supplies in a time efficient manner to meet the needs of an ill/injured crewmember.

3.5.5.5.5 Medical Care Capabilities

The Constellation Architecture shall provide the medical care capabilities specified in Table 3.5-3 (TBR-006-052). [HS6101]

Rationale: Crew health, performance and medical standards as outlined in the Space Flight Crew Health Standards document include definitions of the levels of medical care required to reduce the risk that exploration missions are impacted by crew medical issues, and that long term astronaut health risks are managed within acceptable limits. The levels of care and associated appendixes define the healthcare, crew protection, and maintenance capability required to support the crew as appropriate for the specific mission destination and duration, as well as the associated vehicular constraints. As mission duration and complexity increases, the capability required to prevent and manage medical contingencies correspondingly increases. Very short duration (i.e. transfer missions from e.g. lunar ascent vehicle to CEV (<24 hours) or CEV to ISS or Mars Transit Vehicle) missions, even if outside LEO, will be considered as Level I capability medical requirements.

Table 3.5-3 - - Medical Care Capabilities (TBR-006-052)

Level of Care	Mission	Capability
I	LEO < 8 days	Space Motion Sickness, Basic Life Support, First Aid, Private Audio, Anaphylaxis Response
II	LEO < 30 day	Level I + Clinical Diagnostics, Ambulatory Care, Private Video, Private Telemedicine
III	Beyond LEO < 30 day	Level II + Limited Advanced Life Support, Trauma Care,

		Limited Dental Care
IV	Lunar > 30 day	Level III + Medical Imaging, Sustainable Advanced Life Support, Limited Surgical, Dental Care
V	Mars Expedition	Level IV Autonomous Advanced Life Support and Ambulatory Care, Basic Surgical Care

3.5.5.6 Crew Sleep Accommodations

3.5.5.6.1 Crew Sleep Accommodations

The vehicle shall provide accommodations for crew sleep. [HS6104]

Rationale: *The sleep accomodations requirement ensures that the crew is able to assume a proper configuration to obtain adequate sleep/rest for performance of duties. At a minimum, sleep accommodations include a restrained sleeping position that allows for both full body extension as well as for bringing both knees up to the chest and allows for implementation of HSIR sleep requirements (HS3106, HS3079, and HS5035).*

3.5.6 STOWAGE

3.5.6.1 Stowage Nominal Operation

The vehicle should provide defined stowage locations that do not interfere with normal crew operations. [HS6044]

Rationale: *This requirement is intended to prevent the stowage system from interfering with normal operations such as translation and vehicle control. A "should" is used because constraints on the placement of other items may prevent the design from completely satisfying this requirement.*

3.5.6.2 Stowage Location

The vehicle should provide stowage for equipment and supplies near their intended point of use. [HS6046]

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. A "should" is used because constraints on the placement of other items may prevent the design from completely satisfying this requirement.*

3.5.6.3 Stowage Arrangement

Stowed items should be arranged in functional groups. [HS6047]

Rationale: *To promote efficient retrieval of stowed items, items used in the same procedure are best stowed together. To promote crew comprehension of the stowage plan, similar items are best stowed together. A "should" is used because (i) the previous two notions may contradict one another, and (ii) constraints on the placement of other items may prevent the design from completely satisfying this requirement.*

3.5.6.4 Stowage Reconfiguration

Stowage should be reconfigurable during the mission. [HS6049]

Rationale: *Any stowage system must be flexible enough to accommodate the changes and evolution expected in the stowage plan over the length of a mission. For example, (i) as food is consumed during a mission, food stowage may need to be reallocated for trash, and (ii) during lunar return, lunar samples might be stowed in space originally allocated for water storage.*

3.5.6.5 Stowage Restraints

The vehicle shall provide restraints for stowed items sufficient to prevent them from coming loose under the expected acceleration and vibration environments. [HS6050]

Rationale: *Stowed items must be restrained so that they are not free to move during vehicle motion, under the influence of internal air movement, or after inadvertent contact.*

3.5.6.6 Stowage Hand Operation

Stowage provisions shall be operable without the use of tools. [HS6051]

Rationale: *To maximize the use of crew time, the stowage system must permit crew access and reconfiguration without the use of tools.*

3.5.6.7 Stowage Commonality

Stowage provisions should be common throughout the vehicle. [HS6052]

Rationale: *For example, stowage items such as ISS Cargo Transfer Bags (CTBs) should be interchangeable, so that each bag is usable in each stowage location. Lids, covers, and dividers should be interchangeable. Stowage container sizes that are whole multiples of the smallest container size permit efficient reconfiguration of stowage. This requirement is a "should" because, for example, a stowage container designed for a specific nook within the vehicle or to hold a specific device under ascent loading will not be interchangeable with others.*

3.5.6.8 Stowage Compatibility with Inventory Management

The stowage system shall be compatible with the Program's system for inventory management. [HS6053]

Rationale: *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. The stowage system should help the crew and Mission Operations gather this stowage information, for example by using bar-coded and clearly labeled stowage locations.*

3.5.7 TRASH MANAGEMENT

3.5.7.1 Trash Management Nominal Operations

The vehicle should allocate space for trash stowage that does not interfere with normal crew operations. [HS6054]

Rationale: *This requirement is intended to prevent the trash system from interfering with normal operations such as translation and vehicle control. A "should" is used because constraints on the placement of other items may prevent the design from completely satisfying this requirement.*

3.5.7.2 Trash Management Odor Control

The trash management system shall provide odor control for wet trash. [HS6056]

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

3.5.7.3 Trash Management Contamination Control

The trash management system shall prevent the release of trash into the habitable environment. [HS6057]

Rationale: Many components of trash act as nutrient sources for microorgansisms and quickly increase their concentrations. These mciroorganisms can include medically significant organisms, which could negatively impact crew health and performance. Historically, prevention of the release of microorganisms has been accomplished through layers of containment and addition of trash to the system using methods that do not promote aerosolization of the contents.

3.5.7.4 Trash Management Hazard Containment

The trash management system shall prevent the escape of its contents including crew-generated biological wastes. [HS6058]

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.

3.6 CREW INTERFACES FOR DISPLAYS AND CONTROLS

A vehicle's crew interface is any part of that vehicle through which information is transferred between the crew and the vehicle, whether by sight, sound or touch. Usable, well-designed crew interfaces are critical for crew safety and productivity, and minimize training requirements.

This section provides requirements for crew-controlled processes and the design of crew interfaces for displays and controls. A display is anything that provides visual or auditory information to crewmembers (e.g. label, placard, tone, or display device). A display device is the hardware that displays information to crewmembers. A control is anything that accepts crewmember commands or inputs, whether hardware or software.

The requirements stated herein apply under all operational environmental conditions to which the vehicle may be exposed (i.e., g-forces, vibration, or any combination), and to all crew conditions (i.e., suited, unsuited, seated, unseated, restrained, unrestrained, or any combination).

3.6.1 GENERAL

3.6.1.1 Consistent Crew Interfaces

The vehicle should provide crew interfaces that are consistent in appearance and operation across Constellation systems. [HS7007]

Rationale: The intent of this statement is to ensure as much commonality and consistency as possible across Constellation systems. This will facilitate learning and minimize interface-induced crew error.

3.6.1.2 Labeling

The vehicle shall provide labels for crew interface controls and data items. [HS7036]

Rationale: *Controls and data items must have identifiers (labels) to aid in crew training and error-free operation.*

3.6.1.3 Labeling Standardization

Labels, decals and placards shall be standardized for content and appearance in accordance with Appendix L (TBR-006-063), Labeling and Coding Design Requirements. [HS7078]

Rationale: *The intent of this statement is to ensure as much commonality and consistency according to the appendix. This will facilitate learning and minimize interface-induced crew error.*

3.6.1.4 Nomenclature

Nomenclature related to on-orbit operations shall conform to CxP 70019, the Constellation Nomenclature Plan. [HS7079]

Rationale: *It is imperative for ISS operation that all operations personnel, including all ground controllers and onboard crew members, communicate using common nomenclature that unambiguously and uniquely defines all hardware and software items that may be utilized, the methods by which these are used, and data concerning these items. This nomenclature must also 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. Labeling applicable only to ground-based (nonoperational) functions may use other common technical terms.*

3.6.1.5 Legibility

The vehicle shall provide crew interfaces that are legible under nominal conditions. [HS7044]

Rationale: *Legibility is important for the crew's timely and accurate processing of information. Legibility may vary depending on vehicle conditions (e.g., acceleration, vibration, and lighting) and must be accommodated.*

3.6.1.6 Language

Text shall be written in the American English language as specified by Webster's New World Dictionary of American English, and CxP 70072ANX02, the Constellation Program Management Systems Plan, Annex 02: Common Glossary, Acronyms and Nomenclature list. [HS7064]

Rationale: *The intent of this requirement is to ensure as much commonality and consistency as possible in written text (i.e., language and spelling) across vehicle subsystems and across Constellation systems. This will facilitate learning and minimize interface-induced crew error.*

3.6.1.7 Units of Measure

Units of measure shall be displayed in the International System of Units (SI). [HS7065]

Rationale: *The intent of this requirement is to ensure the use of one unit across Constellation systems for common types of measurements. This will minimize crew training and the potential for conversion errors by crew and ground, which can impact crew and vehicle safety.*

3.6.1.8 Use of Color

The vehicle shall provide an additional cue to convey crew interface information when color is used to convey meaning. [HS7065A]

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 language-based cues (text labels and speech messages), as well as iconic cues presented via the visual, auditory or haptic modalities.

3.6.2 CREW PERFORMANCE

3.6.2.1 Crew Interface Usability

3.6.2.1.1 Crew Interface Usability - Nominal

The vehicle shall provide crew interfaces with usability error rates of less than or equal to 5% (TBR-006-072). [HS7066]

Rationale: For optimal safety and productivity, crew interfaces must support crew performance with minimal errors. Errors will be defined in the context of a usability test (a structured evaluation involving the performance of representative high-fidelity tasks, during which usability data such as completion times, errors, and verbal protocol comments are gathered). Usability errors include missed or incorrect inputs or selections, navigation errors, loss of situational awareness, and inability to complete a task. The usability error rate will be computed as a percentage, (i.e., ratio of number of errors to number of task steps performed).

3.6.2.1.2 Crew Interface Usability - Loss of Crew/Vehicle/Mission

The vehicle shall provide crew interfaces with usability error rates of less than or equal to 1% (TBR-006-071) when performing tasks that can result in a loss of crew, loss of vehicle or loss of mission. [HS7081]

Rationale: Tasks that can result in loss of crew, vehicle or mission are critical, and thus require more stringent usability requirements than nominal tasks. Errors will be defined in the context of a usability test (a structured evaluation involving the performance of representative high-fidelity tasks, during which usability data such as completion times, errors, and verbal protocol comments are gathered). Usability errors include missed or incorrect inputs or selections, navigation errors, loss of situational awareness, and inability to complete a task. The usability error rate will be computed as a percentage, (i.e., ratio of number of errors to number of task steps performed).

3.6.2.2 Crew Cognitive Workload

3.6.2.2.1 Workload Measures - Nominal

The vehicle shall provide crew interfaces that result in a workload rating of 40 (TBR-006-064) or lower on the NASA-TLX Workload Scale when used to perform any anticipated task. [HS7080]

Rationale: The intent of this requirement is to ensure that the crew is not overloaded by nominal or single-failure tasks. The TLX workload rating assessment technique is the most widely used workload measurement tool in operational settings similar to spacecraft vehicle *operation. Workload may be lowered throughout a combination of task simplification, automation, and user-interface design.*

3.6.2.2.2 Workload Measures - "Loss of Crew/Vehicle"

The vehicle shall provide crew interfaces that result in a workload rating of 30 (TBR-006-065) or lower on the NASA-TLX Workload Scale when used to perform tasks that can result in a loss of crew or loss of vehicle. [HS7001]

Rationale: The intent of this requirement is to ensure that the crew is not overloaded by nominal or single-failure tasks. The TLX workload rating assessment technique is the most widely used workload measurement tool in operational settings similar to spacecraft vehicle operation. Workload may be lowered through a combination of task simplification, automation, and user-interface design. A single-failure process is one which must be managed by the crew in a timely manner, but which does not have immediate intra-or inter-system mission-threatening impacts. This is not to be confused with a "single-point" failure.

3.6.2.2.3 Workload Measures - "Loss of Mission"

The vehicle shall provide crew interfaces that result in a workload rating of 40 (TBR-006-066) or lower on the NASA-TLX Workload Scale when used to perform tasks that can result in a loss of mission. [HS7002]

Rationale: The intent of this requirement is to ensure that the crew is not overloaded by tasks. The TLX workload rating assessment technique is the most widely used workload measurement tool in operational settings similar to spacecraft vehicle operation. Workload may be lowered through a combination of task simplification, automation, and user-interface design. A contingency or multiple-failure operational scenario is one which must be managed by the crew in a timely manner, and involves either multiple unrelated system malfunctions, or a single "root-cause" malfunction that has either multiple associated "downstream" equipment and/or subsystem failures or multiple cross-system impacts.

3.6.2.3 Handling Qualities

3.6.2.3.1 Handling Quality ratings - "Loss of Crew/Vehicle"

The vehicle shall have handling quality ratings of 1 or 2 on the Cooper-Harper Scale for tasks that can result in loss of crew or loss of vehicle. [HS7003]

Rationale: The intent of this requirement is to ensure that the crew is able to easily control the vehicle or any vehicle systems that require manual operation under nominal or single-failure conditions. The Cooper-Harper scale is the most commonly used handling qualities rating scale. Handling qualities may be improved through a combination of task simplification, automatic control, and good user-interface design.

3.6.2.3.2 Handling Quality ratings - "Loss of Mission"

The vehicle shall have handling quality ratings of 1, 2 or 3 on the Cooper-Harper Scale for tasks that can result in loss of mission. [HS7004]

Rationale: The intent of this requirement is to ensure that the crew is able to easily control the vehicle or any vehicle systems that require manual operation under contingency or multiple-failure conditions.

3.6.3 DISPLAY AND CONTROL LAYOUT

3.6.3.1 Viewing Requirements

3.6.3.1.1 Field of View

The vehicle shall locate displays and controls, which are viewed for operation, within the field of view of the crew using those displays and controls to perform their tasks. [HS7010]

Rationale: *Displays and controls must be visible to the person using them during all phases of flight and under all conditions in which they are required. The term "perform their task" is meant to include both monitoring and operating.*

3.6.3.1.2 Two-crew Operations

The vehicle shall locate displays and controls such that two operators can view each other's operations for functions that are critical. [HS7010A]

Rationale: *This requirement is intended to facilitate a 2-crew operations concept, which provides redundancy in cockpit decision-making. In the 2-crew operations concept, the actions of the crewmember performing the task can be seen and verified by the other crewmember. As a counter-example, many Shuttle electrical and hydraulic controls can only be seen or operated by the pilot crewmember during the critical ascent phase. This requirement is not intended to override the requirement that the vehicle be operable by a single crewmember.*

3.6.3.1.3 Viewing Critical Displays and Controls

The vehicle should locate critical displays and controls near the center of the crew's field of view. [HS7018]

Rationale: *The operator needs to be able to quickly visually locate critical displays and controls in order to address problems.*

3.6.3.1.4 Viewing Frequently Used Displays and Controls

The vehicle should locate frequently used displays and controls near the center of the operator's field of view. [HS7018A]

Rationale: *The operator needs to be able to quickly visually locate frequently used displays and controls in order to optimize performance, and decrease crew task performance times.*

3.6.3.1.5 Obscured Controls

Controls that are intended for out-of-view operation shall be spatially or tactually distinct from one another. [HS7067]

Rationale: *When the crew inadvertently operates the wrong control, serious errors can result. Controls designed to be out of view while being operated must 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.*

3.6.3.2 Reach Requirements

3.6.3.2.1 Functional Reach Envelope

The vehicle shall locate controls within the functional reach envelope of the crew using those controls to perform their tasks. [HS7019]

Rationale: *Controls have to be within the operator's reach envelope under all vehicle conditions (e.g., g-loads, vibration) and crew conditions (e.g., suited, seated, un/restrained). Controls can include display devices such as touchscreens.*

3.6.3.2.2 Reach for Critical Controls

The vehicle should centrally locate critical controls within the functional reach envelope. [HS7021]

Rationale: *During the design process, tradeoff's of location of critical controls must be made, however all controls will be required to be within the functional reach envelope of the crew. This requirement is intended to encourage the design of a layout that optimizes operations in the cockpit. A "should" is used here because optimization is an iterative process.*

3.6.3.2.3 Reach for Frequently Used Controls

The vehicle should centrally locate frequently used controls within the functional reach envelope. [HS7021A]

Rationale: *During the design process, tradeoff's of location of frequently used controls must be made, however all controls will be required to be within the functional reach envelope of the crew. This requirement is intended to encourage the design of a layout that optimizes operations in the cockpit. A "should" is used here because optimization is an iterative process.*

3.6.3.3 Display and Control Grouping

3.6.3.3.1 Functional Related Displays and Controls

The vehicle should locate functionally related displays and controls near one another. [HS7022]

Rationale: *This requirement is intended to encourage the design of a layout that optimizes operations in the cockpit. A "should" is used here because optimization is an iterative process.*

3.6.3.3.2 Successive Operation of Displays and Controls

The vehicle should locate displays and controls operated in quick succession near one another. [HS7023]

Rationale: *Rapid, error-free operation, and quick comprehension of system status are all improved by well-designed co-location of related controls.*

3.6.3.4 Control Spacing

3.6.3.4.1 Control Spacing For Suited Operations

The vehicle shall space controls that are intended to be used by a pressurized-suited crewmember such that they can be operated by a pressurized-suited crewmember using those controls to perform their tasks. [HS7024]

Rationale: "Suited Operations" refers to the finite set of tasks that must be performed in a suit. Control layout must 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, acceleration). Insufficient spacing may lead to inadvertent operation of an adjacent control.

3.6.3.4.2 Control Spacing for Unsuited Operation

The vehicle shall space controls that are intended to be used by an unsuited crewmember such that they can be operated by an unsuited crewmember using those controls to perform their tasks. [HS7925]

Rationale: Even lightly clothed crewmembers may have difficulty operating controls under expected conditions (e.g., g loads, vibration, acceleration). Insufficient spacing may lead to inadvertent operation of an adjacent control.

3.6.4 DISPLAYS

3.6.4.1 Display Content

3.6.4.1.1 Task Oriented Displays

The vehicle shall provide task-oriented displays. [HS7059]

Rationale: "Task-oriented" displays include all the information required to complete a task, and are designed specifically to help the crew perform key or frequently performed tasks. They consist of information from all of the different systems involved in the task. This allows the crew to quickly and efficiently perform a task as opposed to crew having to use multiple system displays to perform a task. Examples of task displays are (i) a primary flight display and (ii) a rendezvous display. Providing task-oriented displays allows for efficiency and ease of operation.

3.6.4.1.2 Subsystem Orientated Displays

The vehicle shall provide subsystem-oriented displays. [HS7060]

Rationale: "Subsystem" refers to an operationally specific component, such as the Environmental Control and Life Support subsystem. "Subsystem-oriented" displays include all the key information for a subsystem, and are intended to help the crew monitor system health and status. Subsystem displays allow the operator to see the state of a single subsystem at a glance, and aid in troubleshooting. They also allow the crew to perform tasks that were not originally envisioned. Providing subsystem-oriented displays allows for efficiency and ease of monitoring.

3.6.4.1.3 Viewing Simultaneous Task Information

The vehicle should provide the display area necessary to present all of the information required for a task simultaneously (i.e., without toggling among displays). [HS7060A]

Rationale: Without sufficient display devices (e.g. screens), it will be difficult to present the crew with enough information to control a complex spacecraft.

3.6.4.1.4 Viewing Simultaneous Critical Task Information

The vehicle shall provide display area required to simultaneously display critical task information to a single operator. [HS7070]

Rationale: Rapid response to mission-critical tasks will require simultaneous display of multiple sources of information. Without sufficient display devices (e.g. screens), it will be difficult to present the crew with enough information to control a complex spacecraft. Given a large display device the number of devices required might be one; with smaller display devices, the number of devices may increase.

3.6.4.2 Display Hierarchy

3.6.4.2.1 Location within the Display Hierarchy

Displays shall provide the crew with the location of the current display within the display hierarchy. [HS7061]

Rationale: The crew must have situational awareness of where they are in the display hierarchy to maintain efficiency during navigation through the information management system.

3.6.4.2.2 Access Within the Display Hierarchy

Displays should provide a method for the crew to have quick access to any level of the display hierarchy at any time. [HS7071]

Rationale: The crew should have quick access to any level of information to perform their task efficiently.

3.6.4.3 System Feedback

3.6.4.3.1 State Change

Data across vehicles shall be updated for display within 1.0 second (TBR-006-029) of a state change. [HS7072]

Rationale: The recommended response time of 1.0 second applies for user-system feedback (Nielsen, 1993). The intent of this requirement is to provide the crew with current information in the event the same display is called up on multiple display devices (i.e. all users need to see the same data) on different systems (i.e., on CEV and LSAM).

3.6.4.3.2 Lost Data

The vehicle shall inform the crew when a displayed data parameter is unavailable. [HS7072A]

Rationale: Feedback on data that is unavailable (i.e., lost or stale) is important to the crew for accurately weighing data during trouble-shooting and decision-making.

3.6.5 HARDWARE AND SOFTWARE CONTROLS

3.6.5.1 Control Operation

3.6.5.1.1 Compatibility of Movement

Controls shall be designed such that the input direction is compatible with the resulting control response. [HS7063]

Rationale: Control-display compatibility is a widely-used design principle. It promotes quick learning of the vehicle's input-reponse characteristics, and error-free operation of vehicle and other controls. "Controlled Object" refers to a display element, equipment component, or *vehicle. Compatibility means the control movement matches the expected results (e.g. control motion to the right is compatible with clockwise roll, right turn, increase in volume).*

3.6.5.1.2 Control Feedback

The vehicle shall provide a positive indication of a crew-initiated control activation. [HS7063A]

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.

3.6.5.1.3 Protection Against Inadvertent Activation

The vehicle should protect against inadvertent operation of controls. [HS7063B]

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.

3.6.5.1.4 Protection for Critical Controls

The vehicle shall protect against inadvertent actuation of critical controls using a two step process of two independent crew actions. [HS7063C]

Rationale: A two-step process (e.g., arm-fire) is required to prevent an unintended control action that would result in significant negative consequences. This requirement is not intended to prevent operators from initially selecting the wrong control.

3.6.5.1.5 Coding for Emergency and Critical Controls

The vehicle shall provide coding for emergency and critical controls that is distinguishable from non-emergency and non-critical controls as specified in (TBD-006-013) emergency coding table K-2 in Appendix K. [HS7063D]

Rationale: Coding for emergency and critical controls should allow the operator to distinguish them from other controls. It has been shown that operators react more quickly to simple coding such as colors and pictures, than they do to written labels.

3.6.5.1.6 Restraints for Control Operation

The vehicle shall provide restraints for the crew for operation of controls during reduced gravity. [HS7063E]

Rationale: The crew must have a means of reacting to any required control input forces without letting those forces push him or her away from the control. This helps the crew maintain position and apply required control forces.

3.6.5.2 High-g Operations

3.6.5.2.1 Over 3 g

The vehicle shall place controls used during accelerations above 3 g so that the operator can make control inputs via hand/wrist movements without reaching. [HS7027]

Rationale: During periods of high acceleration, users are potentially prone to error and fatigue if they are required to make gross limb movements to make control inputs. To avoid gross limb movements which become difficult to make accurately above 3 g, controls are placed such that they are reachable and operable by a fully restrained and suited operator without translation of the operator's pelvis and with arms supported and restrained (e.g. side-arm controllers).

3.6.5.2.2 Over 2 g

The vehicle shall place controls used during accelerations between 2 g and 3 g so that the operator can make control inputs via hand/wrist movements and reaches within a forward +/-30 degree (TBR-006-027) cone. [HS7028]

Rationale: During periods of high acceleration, users are potentially prone to error and fatigue if they are required to make gross limb movements to make control inputs. Oblique and lateral limb movement accuracy are particularly vulnerable to the elevated Gx forces anticipated during launch and entry. Controls will be placed such that they are reachable and operable by a fully restrained and suited operator without translation of the operator's pelvis with either hand/wrist movements or forward arm reaches to minimize any g-force induced errors due to tangential forces on the arm (e.g. side-controllers, edge keys on a central display).

3.6.5.2.3 Supports

The vehicle shall provide stabilizing support for operator limbs used for control tasks to allow accurate (TBR-006-025) control inputs and to prevent inadvertent control inputs during accelerations between 2 g and 6 g (TBR-006-024). [HS7029]

Rationale: Operator's arms/legs will require proper support and/or restraint to allow for accurate control during elevated g conditions and to prevent inadvertent control inputs during high-g nominal and abort scenarios.

3.6.6 CREW NOTIFICATIONS AND CAUTION AND WARNING

3.6.6.1 Crew Notifications

3.6.6.1.1 Notifications

The vehicle shall notify the crew when critical crew actions are required. [HS7049]

Rationale: Timely reminders to the crew to perform critical actions are crucial for preventing the occurrence of off-nominal events. Notifications are for actions that are not classified as caution and warning events.

3.6.6.1.2 Manual Silencing

The vehicle shall provide a manual silencing feature for active auditory annunciators. [HS7049A]

Rationale: The crew must have the ability to silence an audible alarm that would otherwise annunciate continuously, to prevent it from interfering with their response to the underlying fault. There are well-known instances of aircraft crews that have been functionally incapacitated by audible alarms that they could not cancel.

3.6.6.1.3 Volume Control for Auditory Annunciations

The vehicle shall provide a volume control from 5 to 100% of maximum for audio channels carrying aural annunciations, with the exception of caution and warning signals. [HS7075]

Rationale: *The crew should have the ability to adjust volume of non-caution and warning signals to make desired signals intelligible. Analogous to safety requirements in commercial aircraft, the crew do not adjust the caution and warning audio levels, they have been adjusted relative to the predicted background noise level. There is provision to silence the alarm, but it must be audible initially per ISO 7731(above the masked threshold).*

3.6.6.1.4 Speech Intelligibility

Auditory speech annunciations and communications shall provide a level of speech intelligibility equivalent to a 90% word identification rate. [HS7076]

Rationale: *This requirement ensures that auditory speech annunciations and communications are sufficiently salient and intelligible. ANSI S.3.5-1969 (TBR-006-057) is a widely accepted standard for measuring the intelligibility of speech communications. The 90% word identification level corresponds to an articulation index (AI) of 0.7 (re Military Standard 1474d).*

3.6.6.1.5 Volume Control for Audio Communications

The vehicle shall provide a volume control from 5 to 100% of maximum for each audio channel carrying voice communications. [HS7077]

Rationale: *The crew should have the ability to adjust volume in order to communicate through scenarios in which multiple crew or Mission Systems personnel are speaking.*

3.6.6.2 Caution and Warning

3.6.6.2.1 Annunciation Hierarchy

The vehicle shall assign off-nominal events into classes including: emergency, warning, caution, and advisory. [HS9029]

Rationale: *Off-nominal events are usually divided into the following four classes to simplify training and user comprehension: emergencies, warnings, cautions, and advisories.*

3.6.6.2.2 Annunciation Prioritization

The vehicle shall prioritize vehicle caution and warning annunciations. [HS9029A]

Rationale: *The prioritization of caution and warning annunciations is required so that when there is more than one off-nominal event, the crew's attention is focused on the most critical.*

3.6.6.2.3 Visual and Auditory Annunciation

The vehicle shall provide visual and auditory annunciations to the crew for emergency, warning, and caution events. [HS9030]

Rationale: *Off-nominal events are usually divided into the following four categories to simplify training and user comprehension: emergencies, warnings, cautions and advisories. The* *use of both visual and auditory sensory modalities is required for redundancy, except for advisories, which may not have an auditory annunciation.*

3.6.6.2.4 Distinctiveness of Annunciations

The vehicle shall provide distinct aural annunciations for emergency, caution, and warning event classes as specified in the (TBD-006-014) Caution and Warning Annunciation Table K-3 in Appendix K. [HS9032]

Rationale: Off-nominal events are usually divided into classes (e.g., emergencies, warnings, and cautions). The use of distinct auditory annunciations for each of the event classes will simplify training and user comprehension. The use of both visual and auditory sensory modalities is required for redundancy.

3.6.6.2.5 Loss of Annunciation Capability

The vehicle shall test for a failure of the visual and auditory annunciators on user request. [HS9032A]

Rationale: Situational awareness and safety require a capability to test the Caution and Warning system. The crew must be aware as soon as possible when the Caution and Warning annunciation system cannot be relied upon. Examples include a light test or smoke alarm test button.

3.6.7 CREW SYSTEM INTERACTION

3.6.7.1 Subsystem State Information

The vehicle shall provide subsystem state information on request. [HS7058]

Rationale: Subsystem state information is information related to the last-known or current condition of an application, process, or data item. State information includes information such as operating mode, position, and system health. This requirement makes all the data available to the crew if they request the appropriate information for trouble-shooting and decision-making. The term "on request" referes to requests by the crew as well as pre-defined system displays (e.g., automatic).

3.6.7.2 System Responsiveness For Discrete Inputs

The vehicle shall provide feedback within 0.1 seconds to the crew that a crew discrete input was received. [HS7058A]

Rationale: 0.1 seconds is an industry standard for key response (MIL-STD-1472F). The crew must have feedback that their input was received quickly enough so they have confidence that the system is working correctly, and that they do not make unnecessary additional inputs.

3.6.7.3 System Responsiveness For Continuous Inputs

The vehicle 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. [HS7058B]

Rationale: This requirement is intended to prevent pilot-induced-oscillation and unnecessary re-actuation of vehicle controls. For example, for many manual piloting tasks, vehicle-induced delays of over 0.1 seconds are considered unacceptable.

3.6.7.4 Request For Information

The vehicle should display information within 1.0 second of the crew request. [HS7058C]

<u>Rationale:</u> 1.0 seconds is an industry standard for user requests (MIL-STD-1472F). Excessive delays in the presentation of information lead to a decrease in crew productivity and an increase in frustration.

3.6.7.5 Request for Critical Information

The vehicle shall display critical information within 1.0 second of the crew request. [HS7058D]

<u>Rationale:</u> 1.0 seconds is an industry standard for user request (MIL-STD-1472F). Excessive delays in the presentation of information lead to an increase in the time required for the crew to respond to changes in vehicle state. This requirement assumes that the display process is already running, and that the crew is merely switching between displays.

3.6.7.6 Menu Update Time

The vehicle shall update menus used for display navigation within 0.5 seconds of crew selection. [HS7058E]

<u>Rationale:</u> 0.5 seconds is an industry standard for menu update (MIL-STD-1472F). In order for the crew to effectively interact with a menu, selected menus must appear quickly.

3.6.7.7 Command Feedback

The vehicle shall provide feedback to the crew within 2.0 seconds that the crew's command is in progress, completed, or rejected. [HS7055]

<u>Rationale:</u> 2.0 seconds is an industry standard for error feedback (MIL-STD-1472F). The crew must have feedback that a step in his or her task has been completed, is in work, or cannot be completed, in order that they be able to continue their procedure, or initiate an off-nominal procedure.

3.6.8 ELECTRONIC PROCEDURES

3.6.8.1 Electronic Procedures System

The vehicle shall provide an electronic procedure system that while executing a proceedure:

1) Displays relevent vehicle data within the electronic procedures step being executed

2) Cues (or makes available) vehicle software commands required to be executed from the proecedure. [HS9025]

<u>Rationale:</u> An electronic procedure system is the most effective way for the crew to access, view, and interact with procedures. The intent is that all procedures are available electronically and that, where appropriate, the operator can view telemetry indications from the same view in which they view procedure steps and select commands cued by the electronic procedure system and located on crew displays.

3.6.8.2 Current Procedure Step

The vehicle shall indicate to the crew which step in an electronically displayed procedure is currently being executed. [HS9026]

Rationale: This requirement prevents the crew from missing steps in a procedure by highlighting the step which requires the crew's attention.

3.6.8.3 Completed Procedure Steps

The vehicle shall indicate to the crew which steps in an electronic procedure have been completed. [HS9027]

Rationale: This requirement prevents the crew from re-executing steps in a procedure by highlighting the steps that have been completed.

3.6.8.4 Crew Notification of Required Procedure Action

The vehicle shall notify the crew whenever crew attention is required to complete an electronically displayed procedure. [HS9028]

Rationale: This requirement brings the crew back into a procedure after another agent has completed its steps, or after the crew has been away from the procedure for a significant time. This is required to prevent crew inattention to procedures that are interrupted, or have many agents performing different steps.

3.7 MAINTENANCE AND HOUSEKEEPING

This section includes requirements for the maintenance and housekeeping of vehicle subsystems and components during flight.

3.7.1 MAINTENANCE

3.7.1.1 Efficiency

3.7.1.1.1 ORU Changeout

The vehicle shall enable ORU changeout and planned equipment reconfiguration by personnel wearing clothing and safety appropriate to the environment and phase of flight, including postlanding. [HS8001]

Rationale: Removing and replacing equipment may need to be done during any phase of flight, in which the vehicle may be in different gravity conditions, and by individuals wearing protective clothing and equipment that may limit mobility. Examples of protective clothing and equipment include flight suits, and Self Contained Atmosphere Protective Ensemble (SCAPE) suits. Equipment includes everything that is planned to be maintained in flight, from the LRU down to the component level. Components may include computer cards, power supplies, or in some cases individual electronic components.

3.7.1.1.2 Maintenance Time per Day

The vehicle shall require less than 2 person-hours per day of preventative maintenance and housekeeping during flight. [HS8002]

Rationale: Flight crew time for productive mission activities is of a premium during flight. Preliminary studies based on ISS operation indicate that 2 person-hours per day of overhead activities is the maximum amount of time that can be allocated without incurring detrimental effects on primary mission activities. The requirement is allocated to the each flight Vehicle (CEV, LSAM, e.g.) individually, not in a docked configuration.

3.7.1.1.3 ORU Maintenance Time

ORUs shall have a total maintenance time for removal and replacement of no more than 3 hours. [HS8003]

Rationale: Crew time is of a premium during flight. System designs should support efficient maintenance. Maintenance includes safing, access, removal, replacement, and closeout back to original hardware configuration. Previous spaceflight experience and engineering judgment by subject matter experts indicate that all of these activities can be accomplished in 3 hours or less if the vehicle is designed to facilitate maintenance.

3.7.1.1.4 Access Points

Controls and maintenance access points should not be located near electrical, mechanical, and other hazards. [HS8026]

Rationale: Keeping hazardous equipment away from nominal work areas is highly desired to mitigate safety risks to the flight and ground crews. This requirement is a "should" because it is recognized that maintainers will need to access all parts of the vehicle and not all hazards can be completely eliminated.

3.7.1.2 Error-Proof Design

3.7.1.2.1 Physical Features

Hardware maintained or reconfigured by the flight crew shall include physical features to prevent improper mounting. [HS8005]

Rationale: Improperly mounting equipment can result in unsafe conditions for flight crews, can increase the risk of loss of crew (LOC), loss of mission (LOM) events, and may cause damage to hardware. Physical features lessen the likelihood of human error. Examples of physical features include supports, guides, size or shape differences, fastener locations, and alignment pins. Physical features are the first line of defense for preventing such errors.

3.7.1.2.2 Labeling and Marking

Equipment shall provide visual indication for correct mounting. [HS8006]

Rationale: Improperly mounted equipment can lead to unsafe conditions for flight and ground crews, can increase the risk of LOC or LOM, and/or may cause damage to hardware. In addition to physical features, labeling or marking mitigates human error. Visual indication might include any marking on or adjacent to the equipment interface, labels, or color coding that provides information about mounting. Unique labeling of equipment provides indication that the equipment to be mounted and the mounting location match.

3.7.1.2.3 Interchangeability

ORUs that are not interchangeable functionally shall not create a hazard if interchanged physically. [HS8007]

Rationale: The intent is to prevent the installation of equipment that may physically fit into a location but that can not perform its necessary function, or that performs a different function that can damage associated system (e.g. two check-valves that are physically identical but open at different pressures).

3.7.1.2.4 Connectors

Connectors shall have physical features that preclude mismating and misalignment. [HS8008]

<u>Rationale:</u> Improper mating or misalignment of connectors can lead to short circuit or open circuit conditions that can reduce the safety of flight and ground crews, can increase the risk of LOC or LOM events, and may cause damage to hardware. Physical features are often used to lessen the likelihood of human error. Physical features to preclude improper mating typically include keying, such that connectors cannot be mated to the incorrect location.

3.7.1.2.5 Visual Indication

The vehicle shall provide an orientation cue for the correct mating of connectors. [HS8045]

<u>Rationale:</u> Labeling of connectors ensures efficient identification of connectors to be mated, which lowers risk of improper mating and optimizes use of crew time. Visual indication might include any marking on or adjacent to the equipment interface, labels, or color coding that provides information about mounting. Identification as a label function is covered in User Interface section of HSIR.

3.7.1.2.6 Connector Mating Indication

Connectors shall indicate mating completion. [HS8046]

<u>Rationale:</u> Incomplete mating can result in short circuit or open circuit that can reduce safety of flight or ground crews, can increase the risk of LOC or LOM events and may damage hardware.

3.7.1.2.7 Unique Identification Labeling

Equipment shall provide labeling for unique identification of the equipment. [HS8047]

<u>Rationale:</u> Labeling of equipment ensures efficient identification, which lowers risk of improper use and optimizes use of crew time.

3.7.1.3 Access

3.7.1.3.1 Disturbance of Equipment

The vehicle should be maintainable without removal of ORU's that are not directly the subject of maintenance activity. [HS8053]

<u>Rationale:</u> Not having to remove ORUs for maintenance tasks will minimize mission maintenance times as well as maximize system availability.

3.7.1.3.2 Access Visual

The vehicle shall provide visual access to crew interfaces during planned maintenance activities. [HS8009]

<u>Rationale:</u> Direct line of sight visual access reduces the likelihood of human error that can occur when blind (by feel) operations or operations requiring the use of specialized tools (e.g., mirrors or bore scopes) are performed. Direct line of sight is intended to be required when the item is being manipulated by the crew. Crew interfaces include items such as connectors and fasteners. Direct line of site for pin inspection is not required, though desired where possible.

This does not apply to blind-mate connectors with guides, which are automatically demated and mated as a piece of equipment is removed and replaced.

3.7.1.3.3 Access Physical

The vehicle shall provide the crew, wearing protective clothing when appropriate, with the work envelope to perform all expected maintenance activities. [HS8010]

Rationale: Adequate access and working space is needed to allow personnel to efficiently access equipment in a way that minimizes the potential for human error or human induced damage. Access, including reach envelope, is required for maintenance activities. Access and work envelope are different for differing tasks. In particular, protective garments may be required by the flight crew and must be accommodated.

3.7.1.3.4 Maintenance Hazard

The vehicle shall be maintainable without causing critical or catastrophic hazards. [HS8015]

Rationale: Access to ORUs must be accomplished without impact to other systems.

3.7.1.4 Failure Notification

3.7.1.4.1 Failure Notification

The vehicle shall alert the crew when flight-critical equipment has failed and when it is not operating within tolerance limits, without removal of that equipment. [HS8016]

Rationale: This provides a means of expediting failure troubleshooting and of ensuring that the crew has adequate situational awareness of what functionality has been lost. The alert in some cases may be a display that includes quantitative data indicating the extent of the out-of-tolerance condition.

3.7.1.5 Circuit Protection

3.7.1.5.1 Dynamic Flight

Fuses shall not be used to protect circuits where reset may be required during dynamic phases of flight. [HS8017]

Rationale: During dynamic portions of flight the crew may need to restore system operation rapidly to maintain vehicle control. The intent of the requirement is to preclude the use of destructible circuit protection devices, such as fuses. Finding, sizing, and replacing fuses takes more time than resetting circuit breakers. Nominal operation of the devices returns the circuit to normal functionality with a single crew task.

3.7.1.5.2 Preference

Circuit breakers should be used in preference to fuses. [HS8018]

Rationale: There are several reasons why circuit breakers are preferred, including the ability to rapidly reset breakers, the elimination of the storage, logistics supply, and training required to provision spare fuses. It is recognized that fuses probably cannot be totally eliminated, but where fuses are used rather than circuit breakers, the decision should be backed up by analysis.

3.7.1.5.3 Replacement without Tools

In-flight replaceable fuses shall be removable and replaceable without the use of tools. [HS8020]

Rationale: The elimination of tools eliminates the mass, volume, logistics supply, and training required to provision the tools. This is not intended to preclude the use of a tool for the access panels that may need to be opened before fuse replacement.

3.7.1.5.4 Replacement without Component Removal

In-flight replaceable fuses shall be removable and replaceable in-flight without requiring removal of other components. [HS8021]

Rationale: The removal of non-failed components to access fuses increases the likelihood of damage to the non-failed components, increases the time required to replace the fuse, and adds unnecessary functional retest of non-failed items. This is not intended to preclude the use of access panels that may need to be opened before fuse replacement.

3.7.1.5.5 Circuit Breaker Resetting

Circuit breakers which may require actuation during critical flight phases shall be operable without the removal or opening of access panels. [HS8022]

Rationale: Circuit breakers for ascent, entry and landing phases of a mission must be operated quickly.

3.7.1.5.6 Trip Indication

The vehicle shall provide an indication to the crew when an in-flight replaceable fuse or circuit breaker has opened a circuit. This requirement does not apply to circuit protection within portable loads. [HS8023]

Rationale: This is to provide a means of expediting failure troubleshooting and to ensure that the crew has adequate situational awareness of what functionality is available and what has been lost.

3.7.1.6 Electrostatic Discharge

3.7.1.6.1 Electrostatic Discharge

Equipment that is susceptible to electrostatic discharge damage during operation or planned in-flight maintenance shall be labeled as sensitive to electrostatic discharge damage. [HS8024]

Rationale: This is intended to notify the operator of possible electrostatic discharge sensitivity of the device, which may damage the equipment.

3.7.1.7 Fasteners

3.7.1.7.1 Fasteners Heads

Tool-operated fasteners removed and replaced by the crew shall have self-centering, anti-cam-out heads. [HS8029]

Rationale: This requirement is intended to exclude slotted fasteners—which are not self-centering—and Phillips fasteners—which require the constant application of force along the axis of the fastener to keep the tool seated in the fastener (i.e. to prevent "cam-out"). This will *reduce the likelihood of fastener stripping, and will make it easier for the crew to perform any in-flight maintenance. Examples of acceptable fasteners are internal hex-head, Torq-Set, Torx and Tri-Wing.*

3.7.1.7.2 Fasteners Number and Variety

The number and variety of fasteners used should be the minimum required to meet stress, bonding, pressurization, shielding, thermal, and safety requirements for items that may be removed by the flight crew. [HS8030]

Rationale: This is intended to balance the flight and ground crew effort required to remove fasteners with the design needs that require the fasteners (to satisfy stress, bonding, pressurization, shielding, thermal, and safety requirements). This implies that analysis is performed to determine the minimum number of fasteners that meets the design needs, and that no more than this number be used. This requirement is also intended to be applied to the variety of fastener head types (e.g. Torq-set, hex-head, etc.).

3.7.1.7.3 Captive Fasteners

Fasteners operated by the crew during maintenance tasks shall be captive. [HS8031]

Rationale: A captive fastener is one which is automatically retained in a work-piece when it is not performing its load-bearing job. Captive fasteners, therefore, do not require the flight crew to restrain and store them during maintenance, and can more easily be installed with one hand, reducing maintenance times and reducing the chance of fastener loss.

3.7.1.8 Fluids

3.7.1.8.1 Equipment Isolation

The vehicle shall provide for isolation of fluids in ORUs during maintenance tasks. [HS8032]

Rationale: Isolation valves and quick-disconnect couplings allow for more efficient system maintenance, permit isolation and servicing, aid in leak detection, and eliminate the need to drain and refill systems.

3.7.1.8.2 Leakage

Fluid isolation features shall not leak hazardous levels of fluid as described in JSC-20584, Spacecraft Maximum Allowable Concentrations (SMAC) for Airborne Contaminants. [HS8034]

Rationale: The leakage of fluids (liquid or gas) is a crew health issues during zero g operations (e.g. inhalation hazard). Additionally, leakage during any mission phase (flight or ground) can cause hazardous conditions, increase housekeeping tasks, and may damage equipment. This requirement is intended to cover both toxic and non-toxic fluids.

3.7.1.9 Tools

3.7.1.9.1 Common Toolset

The system should be maintainable and reconfigurable on orbit using a minimum set of tools that are as common as feasible with the other systems. [HS8037]

Rationale: A minimum set of tools, common with other systems, allows for many maintenance tasks to be performed without a proliferation of unique tools and reduces the *training and support requirements for the system. Proprietary or unusual fasteners should be avoided - ex. design to common internal hex tool versus a new size/shape not commonly found in a tool kit.*

3.7.1.9.2 Tool Clearance

The vehicle shall provide tool clearances for tool installation and actuation for all tool interfaces during in-flight maintenance. [HS8052]

Rationale: *Tools to be used for in-flight maintenance must be identified by the hardware developer, and clearance for its application must be accommodated to ensure that maintenance tasks can be performed.*

3.7.1.9.3 Tool Usage

The vehicle shall be maintained or reconfigured on-orbit using only those tools that can be used by crew per HSIR Table B-17 for the maintenance or reconfiguration task. [HS8054]

Rationale: *It is necessary to ensure that all human-system interfaces do accommodate the entire current and future Minimum Crew Operational Load limits. Analysis and testing provide the opportunity to determine that hardware is within the Minimum Crew Operational Loads limits. Therefore, analysis and testing is necessary to ensure that all current and future crewmembers are able to interface and operate with the system hardware.*

3.7.2 HOUSEKEEPING

3.7.2.1 Design for Cleanliness

3.7.2.1.1 Microbial Contamination

Vehicle interior surfaces shall be compatible for cleaning of bacterial contamination to a level of 500 CFU per 100 cm2 or fewer. [HS8041]

Rationale: *This is intended to ensure that bacterial contamination on spacecraft internal surfaces can be removed to mitigate the risk of such contamination to the crew. The limit is from the ISS Medical Operations Requirements Document, Rev. C.*

3.7.2.1.2 Fungal Contamination

Vehicle interior surfaces shall be compatible for cleaning of fungal contamination to a level of 10 CFU per 100 cm2 or fewer. [HS8042]

Rationale: *This is intended to ensure that fungal contamination on spacecraft internal surfaces can be removed to mitigate the risk of such contamination to the crew. The limit is from the ISS Medical Operations Requirements Document, Rev. C.*

3.7.2.1.3 Condensation Prevention on Interior Surfaces

The vehicle shall limit condensation persistence to 1 hour (TBR-006-0669) a day on surfaces within the internal volume during the mission. [HS8051]

Rationale: *The formation of water condensate on internal surfaces have been demonstrated on Mir and ISS to promote the growth of fungi. Examples of moisture buildup from previous spaceflight missions that resulted in fungal growth include uninsulated cold surfaces* *and designed operations which moisten surfaces (such as a wetting a cloth) without appropriate drying.*

3.7.2.2 Air Filters

3.7.2.2.1 Replacement of Air Filters

The vehicle should allow a crewmember to remove and replace air filters that require in-flight servicing without the use of tools. [HS8043]

Rationale: *Crew time is at a premium during a mission. Tools will not be used in order to minimize the impacts to preventative maintenance, and reduce overall weight.*

3.8 INFORMATION MANAGEMENT

Information management is the act of performing functions with electronic data, including data input, organization, internal processing, storage, dissemination, and disposal. Information management functions are performed by crew and Mission Systems using displays on display devices. This section contains requirements related to information management and the use of electronic data across Constellation systems. Requirements specific to the design of the crew interfaces to these data are found in Section 3.6 Crew Interfaces for Displays and Controls.

3.8.1 GENERAL

3.8.1.1 Crew Operability

The vehicle shall provide methods and tools for the crew to perform information management functions. [HS9021]

Rationale: *Information management functions may need to be performed at times when only the crew can perform them, for example when there is no communication with Mission Systems. Examples of information management functions include: graphing system trend information, composing and sending electronic mail, searching for and within procedures, and viewing training materials. Information management functions do not necessarily reside on the flight avionics system.*

3.8.2 DATA AVAILABLE

3.8.2.1 Data Rate

The vehicle should provide data acquired at a rate that enables the crew and ground personnel to perform tasks. [HS9014]

Rationale: *Different classes of data must be gathered at different minimum rates to be useful to the crew or ground personnel, for example, navigation data might be gathered once per second, payload data once per minute, and routine medical data once per day.*

3.8.2.2 Data Fidelity

The data shall have the fidelity for the crew to perform tasks. [HS9040]

Rationale: *Data fidelity (accuracy, precision, reliability, latency, resolution) is essential for proper vehicle functioning and for the crew to make timely and correct decisions, particularly in critical operations.*

3.8.3 DATA DISTRIBUTION

3.8.3.1 Locations

The vehicle shall provide the crew with data to perform tasks at each workstation where those tasks can be performed. [HS9018]

Rationale: *The crew may choose to perform information management functions at varied locations throughout the vehicle. For example, a crewmember reading an online maintenance schematic may choose to move away from a crewmember having a private medical conference.*

3.8.3.2 Wired Network

The vehicle shall provide a wired distribution system for data. [HS9019]

Rationale: *ISS and Shuttle Program history has shown that wireless connections can be unreliable and hard to troubleshoot; therefore, are not desired as the sole option for critical functions. It is important to have a back-up wired distribution system. This requirement is not intended to preclude the use of a primary wireless distribution system, which would be highly desirable.*

3.8.3.3 Wireless Network

The vehicle shall provide a wireless distribution system for data. [HS9020]

Rationale: *ISS and Shuttle Program history has shown that wireless connectivity is desirable, since it reduces clutter within the vehicle and improves mobility and productivity. Since wire clutter is incompatible with launch and entry activities (such as emergency egress), a wireless solution is especially desirable. This requirement provides the capability for wireless, however it does not dictate that all data be transmitted wirelessly.*

3.8.4 DATA BACKUP

3.8.4.1 Automated Backup

The vehicle shall provide an automatic backup function for safety critical data. [HS9023]

Rationale: *Backup functions are best automated to prevent inadvertent loss of flight critical data, and the unnecessary expenditure of crew and Mission Systems time.*

3.8.4.2 Manual Backup

The vehicle shall provide a data backup function. [HS9041]

Rationale: *It is not necessary to backup all data automatically, however, the crew may choose to backup selected data.*

3.8.4.3 Data Restore

The vehicle shall provide a data restore function. [HS9042]

Rationale: *Backup data must be able to be restored in order to support emergency and critical operations independent of Mission Systems support (e.g., loss of comm).*

3.8.4.4 Information Capture and Transfer

The vehicle shall provide a method for the crew to capture and transfer information from any display in a format that provides mobility and the ability to annotate. [HS9042A]

Rationale: Users must be able to capture the contents of an information display for mobility or to make annotations. The use of alternative technologies such as digital paper, PDAs, or tablet computers would allow annotations to be shared more easily with Mission Systems, but this requirement does not preclude the use of printed material.

3.9 GROUND MAINTENANCE AND ASSEMBLY

This section addresses tasks to be performed by NASA and its launch site contractors, in accomplishment of launch site processing and ground maintenance. Launch site processing includes vehicle assembly (e.g., CLV + CEV) activities which occur within the Outer Mold Line of the Launch Stack, Launch Stack physical integration (e.g., umbilical integration), and launch preparation (e.g., propellant loading). Ground maintenance includes corrective and preventative maintenance activities associated with Line Replaceable Unit (LRU) removal and replacement. These requirements do not apply to unplanned repair at the Launch Site, build activities at the manufacturing site, or potential build up at the launch site prior to system integration (for example, build up of the CEV). The requirements in this section apply only to those aspects of design which are under direct control of the vehicle developers, but not to the design of external GSE and test systems. These requirments do not apply to any powered portable equipment which is intended for flight.

3.9.1 GROUND ANTHROPOMETRY, BIOMECHANICS, AND STRENGTH

3.9.1.1 Ground Processing Worksites

The Constellation Architecture shall provide worksites for launch site processing and maintenance tasks that are sized to be performed by ground crew with anthropometric dimensions for stature that are within the 5th to 95th (TBR-006-060) percentiles of the worker population to strength and lifting. [HS10008]

Rationale: The 5th to 95th (TBR-006-060) is the suggested standard which includes 90% of the population. This range conforms to the recommendations of other ground task standards, including HF-STD-001 and MIL-STD-1472. The anthropometric study on which to base the dimensions is TBR.

3.9.2 GROUND NATURAL AND INDUCED ENVIRONMENTS

<Reserved>

3.9.3 GROUND SAFETY

This section is not intended to be a comprehensive collection of requirements related to the safety. Topics covered in this section include mechanical, electrical, fire and touch temperature hazards. Other safety topics are covered in their respective sections of the document.

3.9.3.1 Ventilation Openings

Ventilation openings within the reach envelope of ground crew during launch site processing shall preclude inadvertent insertion of foreign objects which might damage the contents or injure crew. [HS10027]

Rationale: *Ventilation openings are needed by some flight components. If these components are within the reach envelope of ground crew during performance of assembly and maintenance activities, they should be protected from accidental insertion of tools or body parts. Such insertion could pose a hazard to crew or to the hardware.*

3.9.3.2 Ground Processing Hardware Access

The vehicle shall protect ground crews against injury from sharp edges. [HS10030]

Rationale: *Protection of ground crews from injury controls ground operations costs. In those areas that ground crew would access for ground processing and maintenance, the design should protect them from sharp edges and corners. The intent of this requirement is for a design solution, not an operational solution, as the latter results in expensive recurring costs. The requirement might be met by rounding of edges and corners or by designing flight structure that hides sharp edges and corners from crew access during planned operations. It cannot be met by design of remove-before-flight protective structure.*

3.9.3.3 Hazards Labeling

The vehicle shall provide labels to identify hazards to ground crew or to equipment. [HS10033]

Rationale: *Assembly and ground maintenance tasks can require ground crew to work with equipment that is susceptible to damage or which presents a hazard to the crew. Hazard labels are required for protection of ground crews and to alert ground crews to special susceptibilities of equipment (e.g., electrostatic discharge).*

3.9.4 GROUND ARCHITECTURE

This section contains requirements for the overall layout of the vehicle to aide the ground crew in performing launch processing and assembly. Specific topics include layout of functional areas, translation paths.

3.9.4.1 Work Station Layout Interference

The vehicle should separate functional areas where ground processing activities would detrimentally interfere with each other. [HS10047]

Rationale: *Co-location of unrelated activities could degrade operations resulting in increased workload and operational delays. This consideration will be difficult to meet in a small volume, but every effort should be made to separate functions and capabilities that could operationally conflict with each other, or that produce environmental conditions that will conflict with other tasks--e.g. scape ops with wire testing, soldering next to cleanroom environments.*

3.9.4.2 Work Station Layout Sequential Operations

The vehicle should co-locate functional areas in which sequential ground operations are performed. [HS10048]

Rationale: Co-location of related, functional work areas can reduce transit time, communication errors, and operational delays. This consideration may seem to be met simply because of a vehicle's small size, but every effort should be made to group functions and capabilities supporting a task in as efficient a manner as possible to reduce crew workload. For example,time to build access platforms inside the vehicle could be reduced if all similar operations are performed sequentially in a co-located area before platform removal. "

3.9.5 GROUND CREW FUNCTIONS

<Reserved>

3.9.6 GROUND CREW INTERFACES

A vehicle's ground crew interface is any part of that vehicle through which contact is made or information is transferred between the ground crew and the vehicle, whether by sight, sound or touch. Usable, well-designed ground crew interfaces are critical for ground crew safety and productivity, and minimize training requirements. This section provides requirements for ground crew-controlled processes and the design of ground crew interfaces, including displays, display devices and controls. A display is anything that provides information to crewmembers on a display device. A display device is the hardware that displays information to crewmembers. A control is anything that accepts ground crewmember commands or inputs, whether hardware or software. The requirements stated herein apply to all ground crew launch processing activities, with or without personnel protective equipment (PPE).

3.9.6.1 Labeling

The vehicle shall provide labels for ground crew interface controls and indicators. [HS10039]

Rationale: Controls and data items must have labels to aid in ground crew training and error-free operation.

3.9.6.2 Consistent Crew Interfaces

The vehicle should provide ground crew interfaces that are consistent in appearance and operation across flight systems. [HS10050]

Rationale: The vehicle should provide ground crew interfaces that are consistent in appearance and operation across flight systems. Rationale: The intent of this statement is to ensure commonality and consistency across flight systems. This will facilitate learning and minimize interface-induced ground crew error.

3.9.6.3 Legibility

The vehicle shall provide ground crew labels and displays that are legible under task conditions. [HS10051]

Rationale: Legibility is important for the ground crew's timely and accurate processing of information.

3.9.6.4 Written Text

Language Text shall be written in the American English language. [HS10052]

Rationale: The intent of this requirement is to ensure as much commonality and consistency as possible in written text (i.e., language and spelling) across vehicle subsystems and across flight systems. Exceptions would be acronyms and commonly-understood words and terms that are derived from other languages, where there is no suitable English replacement. This will facilitate learning and minimize interface-induced ground crew error.

3.9.6.5 Use of Color

The vehicle should provide an additional cue to convey ground crew interface information when color is used to convey meaning. [HS10053]

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."

3.9.6.6 Work Envelope Volumes

The vehicle shall provide work envelope volumes needed to perform corrective and preventative mainteinance tasks, as well as assembly and other launch site processing tasks. [HS10002]

Rationale: The flight system components/subsystems (CLV stages, CEV SM & CM, e.g.) must be assembled by the ground crew with sufficient work envelope to accomplish tasks. Many of these tasks will constitute mating of components (bolts, connectors, etc.) across the interface between Elements (CLV 1st: 2nd stage, e.g.) or between systems (CLV: CEV). These envelopes will therefore be identified by Vehicle-level task analyses and documented in ICDs. Corrective and preventative maintenance tasks that are accomplished fully within one Element may be analyzed at the Element level. Guidelines for envelope definition are found in FAA-HF-STD-001 Section 14.1. Sufficient envelope is defined by task analyst using this document and based on anthropometric requirements and task definition. The envelope definition will be concurred with by Level II.

3.9.6.7 Reach Envelope Volumes

The vehicle shall provide reach envelope volumes needed to perform corrective and preventative mainteinance tasks, as well as assembly and other launch site processing tasks. [HS10004]

Rationale: The vehicle components must be designed to be assembled and maintained by the ground crew with sufficient reach envelope to accomplish tasks. Many of these tasks will constitute mating of components (bolts, connectors, etc.) across the interface between Elements (CLV 1st: 2nd stage, e.g.) or between systems (CLV: CEV). These envelopes will therefore be identified by Vehicle-level task analyses and documented in ICDs. Guidelines for envelope definition are found in FAA-HF-STD-001 Section 14.1-14.5 and NASA-STD-3000 Section 3.3.3, as applied to ground crews. Sufficient envelope is defined by task analyst using these documents and based on anthropometric requirements and task definition. The envelope definition will be concurred with by Level II.

3.9.6.8 Ground Crew Visual Access

The vehicle shall provide the ground crew visual access needed to perform corrective and preventative mainteinance tasks, as well as assembly and other launch site processing tasks. [HS10006]

Rationale: The vehicle components must be designed to provide the ground crew with visual access of the tasks to be performed as part of launch system assembly and of corrective and preventative maintenance. That is, all tasks should have the object of the task (bolt, connector, etc.) in the direct line of sight of the ground crewmember performing the task, with the vehicle in the assembled, vertical configuration. The envelopes will be identified by both the subsystem-level and the Vehicle-level task analyses. Guidelines for envelope definition are found in FAA-HF-STD-001, Section 14.2 and MIL-STD-1472, Section

5.6.3.1.5. Mirrors and periscopes should not be required. Sufficient envelope is defined by task analyst, based on anthropometric requirements and task definition, and will be concurred with by Level II.

3.9.7 LAUNCH SITE PROCESSING AND GROUND MAINTENANCE

3.9.7.1 Line Replaceable Units (LRUs)

3.9.7.1.1 LRU Installation

Line Replaceable Units (LRUs) shall include physical features that prevent incorrect installation. [HS10012]

Rationale: Each LRU is verified for flight in its designed orientation and configuration. Not only is functionality of the item at risk if it is improperly installed, structural failure could result. Physical features which ensure proper installation (e.g., supports, guides, size, or shape differences, fastener locations, and alignment pins) will at the same time assure that cables and fluid lines are not improperly stressed and that all fasteners are properly torqued.

3.9.7.1.2 LRU Mounting/Alignment Labels/Codes

Line Replaceable Units (LRUs) shall be labeled or coded to identify proper mounting and alignment. [HS10013]

Rationale: Labels provide contextual information to help assure that ground crew does not attempt to install an LRU incorrectly; such an attempt could damage the LRU or the interfaces on the vehicle. Each LRU is verified for flight in its designed orientation and configuration.

3.9.7.1.3 LRU Interchangeability

Line Replaceable Units (LRUs) that are not interchangeable functionally shall not be interchangeable physically. [HS10014]

Rationale: This requirement addresses installation of the wrong component. While some LRUs may be used for the same function in multiple instances (e.g., redundant strings), many may be physically similar but functionally distinct. In such cases, installation in the wrong location could result in damage to the LRU or to the system it is inserted into. This requirement is intended to preclude such installation in the wrong location.

3.9.7.1.4 LRU Tracking Labels

Line Replaceable Units (LRUs) shall be labeled with a logistics tracking label that uses the same standard as flight hardware. [HS10031]

Rationale: Logistics tracking labels shall be consistent with the programmatic logistics and supportability standards.

3.9.7.1.5 LRU Labeling

Line Replaceable Unit (LRU) and flight components that are part of maintenance and launch site tasks shall be labeled to provide identification. [HS10032]

Rationale: This requirement includes identification of the part, indication of male and female (for fluid connectors), jack or plug (electrical connectors), flow direction for fluid lines, and other similar information critical to assembly and maintenance tasks. The naming used on labels must be consistent with programmatic naming conventions.

3.9.7.1.6 LRU Protrusions

LRU hardware shall have all protrusions that could be used as handles support the weight of the LRU without damage or deformation of the LRU. [HS10042]

Rationale: This requirement is being included to avoid a repeat of the confusion which occurred on the GPC upgrade, where connector protectors were misconstrued as handles and required numerous alerts to ground personnel to not lift the units by the connector protectors.

3.9.7.1.7 LRU Weight Limit

Line replaceable units that are required to be installed by one ground crewperson without ground support equipment shall not exceed the safe weight limit as determined by the NIOSH lifting equation. [HS10045]

3.9.7.1.8 LRU Removal without Component Removal

The vehicle should allow for LRU removal without removing other components. [HS10054]

Rationale: Removing LRUs without having to remove other components may protect against damage, and simplify vehicle maintenance tasks.

3.9.7.1.9 LRU Removal and Replacement

A single maintenance activity (LRU removal and replacement) should be achievable by a single technician (TBR-006-061) within four hours (TBR-006-062) of direct technician labor. [HS8004]

Rationale: System designs should support efficient maintenance. Total maintenance time includes safing, access, removal, replacement, and restoration of original hardware configuration. Combining these task times should result in a maximum total allocated technician time of four hours.

3.9.7.2 Connectors

3.9.7.2.1 Connector Mismating

The vehicle shall have physical features that preclude mismating of connectors that are in the same physical location during launch site processing and corrective and preventative maintenance. [HS10015]

Rationale: Connector similarity could lead to inadvertent mismating, which is the mating of a male plug to the wrong female jack. Mismating can damage pins or mechanisms, or even (once powered or filled with fluids) lead to personnel injury or equipment damage.

3.9.7.2.2 Connector Mating Labels

Connectors in the same physical location which must be mated during launch site processing and maintenance shall have labels defining correct mating. [HS10017]

Rationale: Labels will identify which connector plug is intended to be mated with which jack, as well as proper orientation for mating.

3.9.7.3 Fasteners

3.9.7.3.1 Captive Fasteners

The vehicle should provide captive fasteners for maintenance activities. [HS10026]

Rationale: Captive fasteners for maintenance tasks prevent loss of fasteners. Dropped fasteners could become Foreign Object Debris, which could pose a risk during launch. This could cause injury, impact launch schedule, or damage equipment.

3.9.7.4 Tools

3.9.7.4.1 Toolset

The vehicle shall be assembled and maintained using only those tools identified in the Launch Site Task Tool List, Table 3.9-1 (TBD-006-050). [HS10028]

Rationale: Using a standard tool set for all equipment eliminates the proliferation of unique tools and reduces the training and support requirements for the ground crews. Specialty tools require special logistics tracking (which adds to operations costs) and could become lost, postponing maintenance and requiring replacement at a high cost per unit.

3.9.7.4.2 Tool Clearances

The vehicle shall provide tool clearances for tool installation and actuation for all tool interfaces during in-flight maintenance. [HS10024]

Rationale: Verification shall be by analysis. Tool interfaces shall be assessed and the allowance for the specified tool shall be analyzed, through the entire tool use envelope. Verification shall be complete when all tool interfaces have been shown to be in compliance.

3.9.7.5 Circuit Protection

3.9.7.5.1 Fuse/Circuit Indication

The vehicle shall provide indication to the ground crew when a fuse or circuit breaker has opened a circuit. [HS10010]

Rationale: If a circuit has a protection device (e.g. fuse, circuit breaker), the potential exists that the device will need to be replaced or reset by ground crew. To facilitate these tasks, these devices must provide indication of their state to the ground crew.

3.9.7.6 Access

3.9.7.6.1 Maintainability without Deintegration

The vehicle shall not require deintegration or demating of previously tested and certified interfaces during corrective and preventative maintenance. [HS10001]

Rationale: The integrated design of the vehicle must be such that ground crew is able to maintain the components (subsystems, Elements) in the integrated vehicle state and orientation. The intent is to preclude deintegration of the Elements or their subsystems during or after vehicle assembly. Such deintegration would constitute an extremely expensive and recurring addition to ground operating costs. This can only be accomplished through integrated design, so that the design of one subsystem (e.g., CLV 1st Stage) does not force deintegration of the subsystem it is mated to (CLV 2nd Stage) in order to perform maintenance on the integrated vehicle.

3.9.7.6.2 Maintainability without Disabling Subsystems

The vehicle should not require the disabling of subsystems that are not directly part of the maintenance activity during launch site corrective and preventative maintenance. [HS10009]

Rationale: All maintenance worksites must be designed such that removal and replacement does not disable a functional, certified, and fully-tested component or system. Such disabling of a certified system results in costly retest and recertification, resulting in a larger launch site processing workforce.

3.9.7.6.3 Appropriate Clothing

The vehicle shall provide for launch site processing and corrective and preventative mainteinance by personnel wearing clothing and equipment appropriate to the environment during assembly and maintenance tasks. [HS10011]

Rationale: The flight system components/subsystems (CLV stages, CEV SM & CM, e.g.) must be assemblable and maintainable by the ground crew with sufficient work envelope and other accommodation to accomplish tasks, under the constraints demanded by the task. The constraints for some tasks will include the use of protective equipment. This protective equipment (e.g., SCAPE suits) may be bulky, and the design must accommodate this.

3.9.7.6.4 Inspection Access

Vehicle components that require inspection shall be accessible during launch site processing. [HS10025]

Rationale: Access is required for inspection and must be designed for.

3.9.7.6.5 Cable Access

The vehicle shall provide access to cables for scheduled inspections and maintenance during ground operations. [HS8011]

Rationale: Access to cables is required, to ensure that ground personnel can see and reach cables for inspection and maintenance activities.

3.9.7.6.6 External Service Points

External service points for launch pad operations shall be located within 60 degrees, radially, of the plane between the vehicle and the service structure. [HS8013]

Rationale: *The intent is to ensure that vehicle systems that require late servicing at the launch pad (e.g. filling, draining, purging, bleeding, etc.) can be serviced from the main pad structure without the need for additional service structures or high-risk human tasks. This is a requirement on vehicle design that service points be oriented toward the service structure. Examples of service points are those used for filling, draining, purging, or bleeding.*

3.9.7.6.7 Visual-Line-of-Sight

The vehicle should provide direct line-of-sight visual access to all equipment, except blind-mate connectors, on which maintenance is performed by ground personnel, including maintenance requiring Personal Protective Equipment. [HS8048]

Rationale: *Direct line of site visual access reduces the likelihood of human error that can occur when blind (by feel) operations or operations requiring the use of specialized tools (e.g., mirrors or bore scopes) are performed. PPE may be required for certain maintenance activities and must be accommodated. Direct line of site for pin inspection is not required, though desired where possible. A blind-mate connector is one which is automatically demated and mated as a piece of equipment is removed and replaced.*

3.9.7.7 Damage/Hazard Controls

3.9.7.7.1 Equipment Labels and Codes for Hazards

Vehicle equipment to be accessed during launch site processing and maintenance shall be labeled or coded for hazards to equipment or ground personnel. [HS10018]

Rationale: *Hazard labels are required for protection of ground crews and to alert ground crews to special susceptibilities of equipment. Susceptibilities of equipment include electrostatic discharge, but also direct handling hazards. In the past, structures resembling handles or steps have been used as such by ground crews, when they were not designed to be; such structures and potential Keepout Zones should be identified.*

3.9.7.7.2 Maintenance without Damage

The vehicle shall allow corrective and preventative maintenance without damaging other components. [HS10019]

Rationale: *Deintegration of certified flight components will require costly recertification if disturbed. Requirement is intended to limit such recertification. The intent is to maintain flight configuration for systems that are not part of the maintenance.*

3.9.7.7.3 Isolation Valves

The vehicle shall provide isolation or disconnect valves for subsystems that contain pressurized fluids during launch site processing and ground maintenance. [HS10020]

Rationale: *Isolation or disconnect valves are needed to permit isolation and servicing and to aid in leak detection. These valves will also prevent spillage and release of fluids during removal or replacement.*

3.9.7.7.4 Fluid Spillage Control

The vehicle shall control spillage and the release of fluids during launch site processing. [HS10021]

Rationale: Elements or systems must provide methods for controlling liquid and gas spills during ground assembly and maintenance activities.

3.9.7.7.5 System Safing Controls

The vehicle shall provide controls which allow ground personnel to safe the system prior to performing maintenance. [HS10022]

Rationale: Elements or systems must provide methods for system safing during ground assembly and maintenance activities. Controls may include cut-out switches, warning placards, guards, etc. Note: this requirement may need to be in the safety documentation.

3.9.7.7.6 Equipment Protection

The vehicle should protect equipment susceptible to damage during launch site processing tasks. [HS10023]

Rationale: Components and LRUs which are susceptible to damage during assembly or maintenance activities should be protected from ground crew activities. Structural elements which might be utilized as supports should be either designed to support ground crew-induced loads or be protected in some manner. This includes protrusions that resemble handles or steps but which are not designed to be; use of such protrusions to support either the hardware or the ground crew represents a hazard to both the equipment and personnel.

3.9.7.7.7 Safety Displays

The vehicle shall provide displays that are within the field of view of the launch site personnel performing the task when the task could result in a hazard if not viewed directly. [HS10029]

Rationale: When performance of assembly or maintenance tasks requires that feedback be provided to ground crew (e.g., bolt torqueing of a critical component), the ground crew must have clear view of the display. Absence of such access to displays could result in hazard to ground personnel or hardware.

3.9.7.7.8 Protrusion Label/Support

The vehicle shall design all protrusions that could be used as handles, steps, or hand rails either to support the weight of personnel or clearly labeled as Keep Out Zone. [HS10043]

Rationale: Historical experience with Shuttle and Station has shown that it is important to make it clear which parts of a vehicle may not be used as handles, steps, or handrails so that as ground and flight crews move around the vehicle they do not inadvertently damage delicate portions. Preference should be given to designing to support in areas where ground and flight crews will travel frequently.

3.9.8 GROUND INFORMATION MANAGEMENT

<Reserved>

4 HUMAN-SYSTEM VERIFICATION REQUIREMENTS

4.1 ANTHROPOMETRY, BIOMECHANICS, AND STRENGTH

4.1.1 ANTHROPOMETRY

4.1.1.1 Unsuited

The fit, access, reach, view and operation shall be verified by analysis and test. The analysis shall include review of designs, drawing, flight-like mockups, and flight-like prototypes and extraction of measurements to compare against the information contained in the Tables B-1 through B-7B (TBR-006-030). The analysis shall consist of task and worksite analysis performed on all crew functional areas. The test shall measure the crew while physically interacting with a crew functional area within a flight or flight equivalent mockup. The analysis and test results shall be verified against Appendix B, Tables B-1 through B-7B (TBR-006-030) 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 entire range of unsuited crew can fit, access, reach, view and operate all the human-system interfaces. [HS2001V]

Rationale: It is necessary to ensure that all human-system interfaces do accommodate the entire current and future crew whose body dimensions have a specified range. Inspection provides the opportunity to inspect and measure hardware dimensions that can be compared against the anthropometric dimensional ranges. Task and worksite analyses provide the opportunity to test the interfaces with a limited number of human test subjects. Hence, it will only provide the partial results on the test subjects. Therefore, a population analysis is a necessary analytical method to ensure that all current and future crewmembers are able to interface with the system hardware.

4.1.1.2 Suited

The fit, access, reach, view and operation 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 information contained in the Tables B-7A & B-7B (TBR-006-030). The analysis shall consist of task and worksite analysis performed on all crew functional areas. The test shall measure the crew while physically interacting with a crew functional area within a flight or flight equivalent mockup. The analysis and test results shall be verified against Appendix B, Tables B-7A & B-7B (TBR-006-030) 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 entire range of suited crew can fit, access, reach, view and operate all the human-system interfaces. [HS2002V]

Rationale: It is necessary to ensure that all human-system interfaces do accommodate the entire current and future crew whose body dimensions have a specified range. Inspection provides the opportunity to inspect and measure hardware dimensions that can be compared against the anthropometric dimensional ranges. Task and worksite analyses provide the opportunity to test the interfaces with a limited number of suited human test subjects. Hence, it will only provide the partial results on the test subjects. Therefore, a population analysis is a necessary analytical method to ensure that all current and future crewmembers are able to interface with the system hardware.

4.1.2 RANGE OF MOTION

4.1.2.1 Unsuited

The unsuited crewmember range of motion shall be verified by analysis and test. The analysis shall include the review of designs, drawings, flight-like mockups, and flight-like prototypes and extraction of measurements to compare against the information in Tables B-8, and B9 and B-10 (TBR-006-070). The analysis shall consist of task and worksite analyses performed on all crew functional areas. The test shall measure the crew while physically interacting with a crew functional area within a flight or flight equivalent mockup. The analysis and test results shall be verified against Appendix B, Tables B-8, and B9 and B-10 (TBR-006-070) by means of population analytical methods. The verification shall be considered successful when the analysis and test show the measurements have been met, and that the unsuited crew can physically interact within the crewmember ranges of motion. [HS2003V]

Rationale: It is necessary to ensure that all human-system interfaces do accommodate the entire current and future crew whose ranges of motion have a specified range. Inspection provides the opportunity to inspect and measure hardware dimensions that can be compared against the range of motion ranges. Task and worksite analyses provide the opportunity to test the interfaces with a limited number of human test subjects. Hence, it will only provide the partial results on the test subjects. Therefore, a population analysis is a necessary analytical method to ensure that all current and future unsuited crewmembers are able to interface with the system hardware.

4.1.2.2 Suited

The suited crewmember range of motion shall be verified by analysis and test. The analysis shall include the review of designs, drawings, flight-like mockups, and flight-like prototypes and extraction of measurements to compare against the information in Table B-8, and Tables B-9 through B-10 (TBR-006-070). The analysis shall consist of task and worksite analyses performed on all crew functional areas. The test shall measure the crew while physically interacting with a crew functional area within a flight or flight equivalent mockup. The analysis and test results shall be verified against Appendix B, Tables B-8, and B-9 and B-10 (TBR-006-070) by means of population analytical methods. The verification shall be considered successful when the analysis and test show the measurements have been met, and that the suited crew can physically interact within the crewmember ranges of motion. [HS2004V]

Rationale: It is necessary to ensure that all human-system interfaces do accommodate the entire current and future suited crew whose ranges of motion have a specified range. The test provides the opportunity to measure the crew while physically interacting with the hardware and can be compared against the range of motion ranges. Task and worksite analyses provide the opportunity to test the interfaces with a limited number of human test subjects. Hence, it will only provide the partial results on the test subjects. Therefore, a population analysis is a necessary analytical method to ensure that all current and future suited crewmembers are able to interface with the system hardware.

4.1.3 MASS PROPERTIES

4.1.3.1 Unsuited

Not Applicable

4.1.3.2 Suited

Vehicle systems with human system interfaces shall be verified by analysis to sustain the maximum mass of a suited subject. The analysis shall include the review of designs, drawings, flight-like mockups, and flight-like prototypes and strength computations to compare against the information in Table B-11. The analysis shall be performed to determine if damage will occur on those human system interfaces that are normally subjected to high forces during normal operation and emergency operations. The analysis results shall be verified against Appendix B, Table B-11. The verification shall be considered successful when the analysis shows the vehicle systems with human interfaces accommodate the maximum suited crewmember mass. [HS2006V]

Rationale: Vehicle systems with human-system interfaces shall be verified by analysis and test to sustain the mass properties of a pressurized suited subject. The analysis shall include the review of designs, drawings, flight-like mockups, and flight-like prototypes and extraction of measurements to compare against the information in Table B-11. The analysis shall be performed to determine if damage will occur on those human-system interfaces that are normally subjected to high forces during normal operation and emergency operations. The test shall consist of a set of tasks to assess the operation and structural limit of the human-system interfaces. The analysis and test results shall be verified against Appendix B, Table B-11 by means of population analytical methods. The verification shall be considered successful when the analysis and test show the vehicle systems with human interfaces accommodate the crewmember mass properties.

4.1.4 STRENGTH

4.1.4.1 Maximum Crew Operational Loads - Unsuited

"Maximum Crew Operational Loads" by unsuited crew shall be verified by analysis. The analysis shall include the review of designs, drawings, flight-like mockups, and flight-like prototypes and extraction of measurements to compare against the information in Tables B-17A. The structural analysis shall be performed to determine if damage will occur on those components that are normally subjected to high forces during normal operation and emergency operations. The analysis results shall be verified against Appendix B, Tables B-17A. The verification shall be considered successful when the analysis show the strength measurements have been met, and that the unsuited crewmember can physically interact within the components/systems. [HS2007V]

Rationale: It is necessary to ensure that all human-system interfaces do accommodate the entire current and future crew structural limits. Inspection provides the opportunity to inspect and measure hardware dimensions that can be compared against the structural limits. Task and worksite analyses provide the opportunity to test the interfaces with a limited number of human test subjects. Hence, it will only provide the partial results on the test subjects. Therefore, a *population analysis is a necessary analytical method to ensure that all current and future crewmembers are able to interface with the system hardware.*

4.1.4.2 Maximum Crew Operational Loads - Suited

Not Applicable. [HS2007BV]

4.1.4.3 Minimum Crew Operational Loads - Unsuited

"Minimum Crew Operational Loads" for unsuited crew shall be verified by analysis and test. The analysis shall include the review of designs, drawings, flight-like mockups, and flight-like prototypes and extraction of measurements to compare against the information in Table B-17A. The analysis shall be performed to determine if crewmembers can operate all components. The test shall consist of a set of tasks to test the minimum operational loads required by the components. The analysis and test results shall be verified against Appendix B, Table B-17A by means of population analytical methods. The verification shall be considered successful when the analysis and test show the strength measurements have been met, and that the crewmember can physically interact and operate all components. [HS2008V]

Rationale: It is necessary to ensure that all human-system interfaces do accommodate the entire current and future Minimum Crew Operational Load limits. Analysis and testing provide the opportunity to determine that hardware is within the Minimum Crew Operational Loads limits. Therefore, analysis and testing is necessary to ensure that all current and future crewmembers are able to interface and operate with the system hardware.

4.1.4.4 Minimum Crew Operational Loads - Suited

Not Applicable. [HS2008BV]

4.1.4.5 Crew-Induced Loads

Vehicle components and equipment ability to withstand crew-induced loads are verified by analysis. The analysis shall show that the vehicle components and equipment ability to withstand crew induced loads of 262 N (59 lbf) (TBR-006-003) over 10 cm by 10 cm (4 in by 4 in) square from any direction. The verification shall be considered successful when the analysis shows positive margins of safety for the vehicle components and equipment. [HS2009V]

Rationale: It is necessary to ensure that all human-system interfaces to withstand incidental crew induced loads. Analysis and testing provide the opportunity to determine that hardware can sustain incidental crew induced loads. Therefore, analysis and testing is necessary to ensure that all current and future crewmembers are able to interface and operate with the system hardware.

4.2 NATURAL AND INDUCED ENVIRONMENTS

4.2.1 ATMOSPHERE

4.2.1.1 Atmospheric Quality, Nominal

4.2.1.1.1 Total Pressure

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 pressure control system of the vehicle 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. 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. [HS3004V]

Rationale: No further Rationale required.

4.2.1.1.2 O2 Partial Pressure

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 pressure control system of the vehicle 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. 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. [HS3004BV]

Rationale: No further Rationale required.

4.2.1.1.3 CO2 Partial Pressure

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 pressure control system and the contaminant control system of the vehicle 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. The verification shall be considered successful when the test and analysis data show that the vehicle can maintain the partial pressure carbon dioxide of the internal atmosphere within the ranges described in the requirement. [HS3004CV]

Rationale: No further Rationale required.

4.2.1.1.4 N2 Partial Pressure

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. The verification shall be considered successful when the analysis shows the vehicle can maintain the partial pressure nitrogen of the internal atmosphere within the ranges described in the requirement. [HS3004DV]

Rationale: No further Rationale required.

4.2.1.2 Atmospheric Quality, Contingency, Off-Nominal and Suited

4.2.1.2.1 Total Pressure

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 pressure control system of the vehicle 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. 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 ranges described in the requirement. [HS3005V]

Rationale: No further Rationale required.

4.2.1.2.2 O2 Partial Pressure

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 pressure control system of the vehicle 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. 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. [HS3005BV]

Rationale: No further Rationale required.

4.2.1.2.3 CO2 Partial Pressure

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 pressure control system of the vehicle 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. The verification shall be considered successful when the test and analysis data show that the vehicle can maintain the partial pressure carbon dioxide of the internal atmosphere within the ranges described in the requirement. [HS3005CV]

Rationale: No further Rationale required.

4.2.1.3 Control

4.2.1.3.1 O2 and Total Pressure

The capability to adjust total pressure shall be verified by Test. The test shall include the measurements of total pressure during operation of an integrated vehicle system. The verification shall be considered successful when the test shows the total pressure can be adjusted by the crew within the ranges defined in requirements HS3004 and HS3005. [HS3001V]

Rationale: No further Rationale required.

4.2.1.4 Display

4.2.1.4.1 Composition Reporting

The ability of the vehicle to display of total pressure, partial pressure oxygen, partial pressure carbon dioxide, and partial pressure nitrogen to the crew shall be verified by Demonstration. The Demonstration shall be an observation the vehicle displays during various atmospheric conditions. The verification shall be considered successful when the analysis shows the system can be displayed to the crew. [HS3013V]

Rationale: No further Rationale required.

4.2.1.5 Alerting

4.2.1.5.1 Composition Alerting

The ability of the vehicle to alert the crew when total pressure, partial pressure oxygen, and partial pressure carbon dioxide exceed acceptability limits shall be verified by analysis supported by test. The analysis shall include a review of the vehicle design and the measurements of atmospheric pressure and caution and warning systems under nominal and off-nominal conditions during operation of the integrated vehicle system. At the vehicle or subsystem level, a test shall show that the caution and warning system will provide an alert to the crew when the cabin atmospheric condition limits are exceed for total pressure, partial pressure oxygen, and partial pressure carbon dioxide. The verification shall be considered successful when the analysis and test data show the systems can successfully detect and alert the crew when the constituents exceed limits described in HS3004, HS3004B, HS3004C. [HS3014V]

Rationale: No further Rationale required.

4.2.1.6 Contaminants

4.2.1.6.1 Fungal

The limit of fungal contaminants in the internal atmosphere shall be verified by Analysis. The analysis shall include a review of the vehicle design. The verification shall be considered successful when the analysis shows the fungal contamination within the vehicle can remain below 100 colony forming units/ m3. [HS3006V]

Rationale: No further Rationale required.

4.2.1.6.2 Bacterial

The limit of bacterial contaminants in the internal atmosphere shall be verified by Analysis. The analysis shall include a review of the vehicle design. The verification shall be considered successful when the analysis shows the bacterial contamination within the vehicle can remain below 1000 colony forming units/ m3. [HS3006BV]

Rationale: No further Rationale required.

4.2.1.6.3 Particulate

The limit of particulate in the internal atmosphere shall be verified by Analysis. The analysis shall include a review of the vehicle design. The verification shall be considered successful when the analysis shows the particulate contamination within vehicle can remain below 5 mg/m3. [HS3006CV]

Rationale: No further Rationale required.

4.2.1.6.4 Lunar Dust

The limit of lunar dust in the internal atmosphere shall be verified by Analysis. The analysis shall include a review of the vehicle design and testing of the atmosphere revitalization system.

The verification shall be considered successful when the analysis and tests show the particulate contamination of less than 10 micron size (TBR-006-004) within vehicle can remain below 0.05 mg/m3 (TBR-006-005). [HS3006DV]

Rationale: No further Rationale required.

4.2.1.7 Gaseous Pollutants

4.2.1.7.1 Gaseous Pollutants Limits

Trace atmospheric chemical contamination control shall be verified by analysis. The analysis shall be based on a review of the vehicle design and measurements of trace chemical contaminant concentration buildup as a function of time acquired during an integrated vehicle system offgassing test. The verification shall be considered successful when the analysis shows the vehicle can maintain individual trace atmospheric chemical contaminant concentrations below those contained in JSC 20584. [HS3007V]

Rationale: Multiple precautions must be incorporated into the vehicle design and operation to achieve acceptable air quality. Accomplishing these tasks to meet the requirement can only be verified using inflight samples obtained during missions.

4.2.1.8 Rate of Change of Pressure

4.2.1.8.1 Rate of Change of Pressure Limits

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. The verification shall be considered successful when the analysis indicates the vehicle will not exceed the pressure change described in the requirement. [HS3009V]

Rationale: No further Rationale required.

4.2.1.9 Combustion Products

4.2.1.9.1 Combustion Products Monitoring

The ability of the vehicle to monitor and display atmospheric concentrations of CO, HCN, and HCl in the habitable volume of the vehicle in real time shall be verified by test and analysis. Tests shall show that the atmospheric monitoring instruments correctly determine the gas concentrations and that these concentrations will be correctly displayed in real time in the vehicle. The analysis shall show that the atmospheric composition, pressure, circulation, and availability to the monitoring instruments provide the correct measurement of the gas concentrations. The verification shall be considered successful when the tests and analysis show that the atmospheric concentrations of CO, HCN, and HCl in the habitable volume of the vehicle combustion products will be monitored and displayed in real time. [HS3012AV]

Rationale: The measurement capabilities of the atmosphere monitor instruments can be verified by tests outside the vehicle. The atmospheric concentration displays may be part of stand-alone instruments, so that the displays can also be verified outside the vehicle, or they may be integrated with other vehicle display systems and require a vehicle test. Analysis of atmosphere conditions and circulation and presentation to the instruments is needed to confirm their performance in the vehicle.

4.2.1.9.2 Combustion Products Measurement

The ability of the vehicle to measure the specified atmospheric gas concentrations in real time in the required ranges shall be verified by test. The test shall show that the atmospheric monitoring instruments correctly determine the atmospheric gas concentrations over the given ranges. The verification shall be considered successful when the test shows a real time capability for the measurement of atmospheric concentrations of the specified toxic combustion products over the specified ranges. [HS3012BV]

Rationale: The measurement capabilities of the atmosphere monitor instruments can be verified by tests outside the vehicle. Accuracy of measurement is not specified, so commercial laboratory instrument accuracy can be assumed.

4.2.1.9.3 Acid Gas Monitoring

The ability of the vehicle to monitor hydrogen cyanide (HCN) and hydrogen chloride (HCl) at all locations throughout the habitable volume shall be verified by inspection and analysis. The inspection shall examine verification compliance data for HS3012A to confirm the ability of the vehicle to monitor atmospheric concentrations of HCN, and HCl in the habitable volume of the vehicle. The analysis shall show that the atmospheric circulation and testing is such that these gases are monitored at all locations throughout the habitable volume. The verification shall be considered successful when the analysis shows the ability of the vehicle to monitor hydrogen cyanide (HCN) and hydrogen chloride (HCl) at all locations throughout the habitable volume. [HS3012CV]

Rationale: Analysis of atmosphere circulation and sampling is needed to confirm the ability to monitor these gases at all locations throughout the habitable volume. Requirement [HS3012C] is partly included in [HS3012A] but is added to emphasize the need for monitoring two of the toxic combustion products at all locations.

4.2.1.9.4 Carbon Monoxide Alert

The ability of the vehicle to alert the crew whenever the carbon monoxide (CO) concentration exceeds the lower limit in HS3012B shall be verified by inspection and test. The inspection shall examine verification compliance data for requirement HS3012B to confirm the instrumentation correctly detects carbon monoxide (CO) concentration at and above the lower detectable limit in HS3012B. The test shall show that the detection of carbon monoxide (CO) exceeding the lower limit produces an alarm to alert the crew. The verification shall be considered successful when the inspection and test show that the alert system alerts the crew whenever the carbon monoxide (CO) concentrations exceed the lower limit in HS3012B. [HS3012DV]

Rationale: The CO alarm may be part of the CO detection instruments, or may be integrated with other vehicle systems and require an on vehicle test.

4.2.1.10 Hazardous Chemicals

4.2.1.10.1 Toxic Level 3

The use of Toxic Hazard Level 3 or lower chemicals in the habitable volume of the vehicle shall be verified by Analysis. The analysis shall include a design review of the materials and chemicals selected for vehicle construction and their use in the operation of the vehicle. The verification shall be considered successful when the analysis shows Toxic Hazard Level 3 or lower chemicals are the only chemicals used in the habitable volume of the vehicle. [HS3015V]

Rationale: The verification process involves 3 steps:

1) identification of potential compounds that could decompose in environmental systems, 2) identification of the products of decomposition if any, and 3) determination if any decomposition products would be toxic at the concentrations anticipated.

4.2.1.10.2 Toxic Level 4

The prevention of Toxic Hazard Level 4 chemicals from entering the habitable volume of the vehicle shall be verified by Analysis. The analysis shall include a design review of the materials and chemicals selected for vehicle construction and their use in the operation of the vehicle. The analysis shall identify the location of any Tox 4 chemicals, and their levels of containment. The verification shall be considered successful when the analysis shows Tox 4 chemicals cannot enter the habitable volume of the vehicle. [HS3015AV]

Rationale: No further Rationale required.

4.2.1.10.3 Decomposition

The prevention of chemical decomposition into hazardous compounds shall be verified by analysis. The analysis shall include an integrated review of the final flight materials and chemicals selected for vehicle construction. The analysis shall identify all hazardous compounds and shall document these items in the Material Usage Agreement (MUA) process. The verification shall be considered successful when the analysis shows that no chemicals and/or materials have been used in the vehicle's design or fabrication that can be broken down or converted into compounds that threaten crew health. [HS9037V]

Rationale: The verification process involves 3 steps: 1) identification of potential compounds that could decompose in environmental systems, 2) identification of the products of decomposition if any, and 3) determination if any decomposition products would be toxic at the concentrations anticipated.

4.2.1.11 Crew Protection

4.2.1.11.1 Personal Protective Equipment

The provision for stowage space of personal protective equipment (PPE) shall be verified by inspection. The inspection shall include a review of the vehicle design to ensure accessible stowage space for PPE. The inspection shall identify the presence of PPE. The verification shall be considered successful when the inspection identifies adequate stowage space and the presence of PPE. [HS3016V]

Rationale: No further Rationale required.

4.2.1.11.2 Contingency Breathing Apparatus

Breathing gas provisions shall be verified by analysis and inspection. The analysis shall determine the amount of breathing gas required for contingency provision to the entire crew. The inspection shall identify the amount of breathing gas provided in the vehicle for contingency use. The verification shall be considered successful when the analysis and inspection show that the amount of breathing gas provided in the vehicle is equal to or greater than the amount required. [HS3017AV]

Rationale: No further Rationale required.

4.2.1.11.3 Crew Communication

The presence of communication capability shall be verified by Demonstration. The Demonstration shall include communication between individuals using the contingency breathing apparatus and flight or flight-like hardware. The verification shall be considered successful when the Demonstration shows communication. [HS3017V]

Rationale: No further Rationale required.

4.2.1.11.4 Mission Systems Communication

The presence of communication capability shall be verified by test. The test shall include communication between vehicle and ground individuals using the flight or flight-like contingency breathing apparatus connected to a flight or flight-like communication system. The verification shall be considered successful when the test shows communication between the contingency breathing apparatus and Mission Systems. [HS3017BV]

Rationale: Protection of ground crews from injury controls ground operaitons costs. In those areas that ground crew would access for ground processing and maintenance, the design should protect them from sharp edges and corners. The intent of this requirement is for a design

4.2.2 POTABLE WATER

4.2.2.1 Quality

4.2.2.1.1 Physiochemical Limits

Physiochemical 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 preparation of potable water and crew recovery. Samples shall be collected from multiple ports throughout the water system to demonstrate compliance. These tests shall be conducted using standard laboratory techniques described in Standard Methods for Examination of Water & Wastewater, American Public Health Association shall be used. The verification shall be considered successful when test data is compliant with Table 3.2-4. [HS3019V]

Rationale: Comprehensive inflight analysis is impractical. Verification will be completed by ground longevity testing of the full-scale water system. Previous experience has shown that engineering design analysis cannot account for all factors affecting water quality and full-scale tests are necessary to ensure water quality. Water quality is affected by long term contact with materials of construction and other design aspects that would only be revealed in a high fidelity integrated ground test.

4.2.2.1.2 Microbial Limits

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 preparation of potable water and crew recovery. Samples shall be collected from all locations throughout the water system that the crew may be exposed to demonstrate compliance. These tests shall be conducted using standard laboratory techniques described in Standard Methods for Examination of Water & Wastewater, American Public Health Association shall be used or alternate approved methodology that will provide comparable data. The verification shall be considered successful when test data are compliant with Table 3.2.2-2. [HS3019AV]

Rationale: Comprehensive in-flight analysis is impractical. Verification will be completed by ground longevity testing of the full-scale water system. Previous experience has shown that engineering design analysis cannot account for all factors affecting water quality and full-scale tests are necessary to ensure water quality. Water quality is affected by the growth of microorganisms during water storage and by other design aspects that would only be revealed in a high fidelity integrated ground test. Analyses not part of standard methods must be approved by the JSC microbiology group prior to use.

4.2.2.2 Quantity

4.2.2.2.1 Potable Water On-orbit Consumption

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 all vehicle configurations. The verification shall be considered successful when the analysis shows sufficient volume and mass capacity for stowage of potable water in the amount of 5.5 lbs (2.5 kg) of potable water per crewmember per mission day, (in addition to other potable water requirements), utilizing maximum crew size and maximum mission duration. [HS3025V]

Rationale: No further Rationale required.

4.2.2.2.2 Potable Water Fluid Loading

The provisioning of the specified quantity of potable water for re-entry fluid loading shall be verified by analysis. The analysis shall determine the amount of potable water stowage on the vehicle for all vehicle configurations. The verification shall be considered successful when the analysis shows sufficient volume and mass capacity for stowage of potable water in the amount of 1.0 kg (2.2 lbs) of potable water per crewmember (in addition to other potable water requirements), considering maximum crew size. [HS3026V]

Rationale: No further Rationale required.

4.2.2.2.3 Potable Water Post Landing

The provisioning of the specified quantity of potable water for post-landing recovery shall be verified by analysis. The analysis shall determine the amount of potable water stowage on the vehicle for all vehicle configurations. The verification shall be considered successful when the analysis shows sufficient volume and mass capacity for stowage of potable water in the amount of 4.5 kg (9.9 lbs) of potable water per crewmember (in addition to other potable water requirements), considering maximum crew size. [HS3027V]

Rationale: No further Rationale required.

4.2.2.2.4 Potable Water Personal Hygiene Water

The capability of the vehicle to provide 0.4 kg (0.88 lbs) (TBR-006-006) of potable water per crewmember-day shall be verified by Analysis. The analysis include a design review of the vehicle to show that this quantity of water is available for personal hygiene (the water in pre-wetted towels counts towards this). The verification shall be considered successful when the analysis shows sufficient volume and mass capacity for supply of this volume of potable water, utilizing maximum crew size and maximum mission duration. [HS3028V]

Rationale: No further Rationale required.

4.2.2.2.5 Potable Water Rate

The capability of the vehicle to provide potable water to fill a 237 milliliter (8 ounce) water bag in less than 30 seconds every minute shall be verified by Test. Testing shall include filling of water bags using the potable water system. The verification shall be considered successful when the test shows the water system can fill a 237 milliliter (8 ounce) water bag in less than 30 seconds every minute (TBR-006-073). [HS3029V]

Rationale: No further Rationale required.

4.2.2.3 Water Temperature

4.2.2.3.1 Cold Water

Not Applicable

4.2.2.3.2 Hot Water

The capability of the vehicle to provide potable water between 68.3 ºC (155 ºF) and 79.4 ºC (175 ºF) shall be verified by Test. Testing will include measurements of the temperature of the hot potable water. The verification shall be considered successful when the test shows the system can provide water at this temperature. [HS3031V]

Rationale: No further Rationale required.

4.2.2.3.3 Potable Water for Personal Hygiene

Not Applicable

4.2.2.4 Water Sampling

4.2.2.4.1 Water Sampling Pre- and Post-Flight

Access to the vehicle potable water systems for sample collection shall be verified by Inspection. The inspection will include a review of vehicle and potable water system designs to ensure access to the water supply during ground processing, on the launch pad, and post-flight. The verification shall be considered successful when the inspection shows access for potable water sample collection during ground processing, on the launch pad, and post-flight. [HS3034V]

Rationale: Numerous factors can quickly affect water quality, as has been demonstrated in previous flight programs. Thus, access to the water supply as close to launch as practical will allow sampling to confirm this quality. As in-flight analysis is impractical, access for post-flight analysis is required to confirm water quality throughout the flight.

4.2.3 THERMAL ENVIRONMENT

4.2.3.1 Atmospheric Temperature

4.2.3.1.1 Nominal

The capability of the vehicle to maintain temperature shall be verified by Analysis. The analysis shall include a review of the vehicle 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. The verification shall be considered successful when the analysis demonstrates that the vehicle can maintain the temperature between 18 ºC (64.4 ºF) to 27 ºC (80.6 ºF) during all mission phases. [HS3036V]

Rationale: No further Rationale required.

4.2.3.1.2 Contingency

The maintenance of the energy stored by the crew shall be verified by analysis. Analysis shall include a review of the vehicle design and demonstration of the vehicle atmospheric control system in a high fidelity test. The verification shall be considered successful when the analysis shows that the Constellation Architecture can maintain Q stored within -4.1 kJ/kg (-1.76 Btu/lb) and 4.7 kJ/kg (2 Btu/lb). [HS3057V]

Rationale: No further Rationale required.

4.2.3.2 Relative Humidity

4.2.3.2.1 Relative Humidity

The capability of the vehicle to maintain the relative humidity between 25 and 75 percent inclusive 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. The verification shall be considered successful when the analysis demonstrates that the vehicle can maintain the relative humidity between 25 and 75 percent inclusive for all mission phases, excluding suited operations, ascent, entry, landing, and post landing. [HS3046V]

Rationale: No further Rationale required.

4.2.3.3 Ventilation

4.2.3.3.1 Ventilation - In-flight

The capability to maintain a ventilation rate within the vehicle shall be verified by Analysis. 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 no 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 verification shall be considered successful when the analysis establishes the ventilation rate remains between 0.079 m/sec (0.26 ft/s) and 0.61 m/sec (2.0ft/s) (TBR) at a distance measured more than 0.15 m (6 inches) from the vehicle walls during all mission phases except during depressurized cabin conditions, or while the crew is not present. [HS3047V]

Rationale: No further Rationale required.

4.2.3.3.2 Supplemental Ventilation

The environment for temporary maintenance activities in areas not in the normal habitable volume shall be verified by test. The test shall be performed in a high fidelity mockup of the vehicle, and shall account for expected crewmember metabolic loads. The verification shall be considered successful when the test shows that the environment is controlled as defined in Table 3.2-2, Table 3.2-3, and HS3046. [HS3050V]

Rationale: No further Rationale required.

4.2.3.4 User Control

4.2.3.4.1 Temperature Set-points

The increments of set-points for temperature control shall be verified by Inspection. The Inspection shall include a review of the set point control. The verification shall be considered successful when the set-point control shows the temperature can be adjusted in 1°C (1.8° F) or less increments within the ranges defined in HS3036. [HS3053V]

Rationale: No further Rationale required.

4.2.3.4.2 Temperature Set-Point Adjust

The capability of the crew to adjust the set-point for atmospheric temperature shall be verified by Test. The test shall include the measurements of temperature during operation of an integrated vehicle system. The verification shall be considered successful when the test shows the temperature can be adjusted by the crew between 21 °C (69.8 °F) (TBR-006-018) and 27 °C (80.6 °F). [HS3051V]

Rationale: No further Rationale required.

4.2.3.4.3 Temperature Display Step Sizes

Display step sizes shall be verified by inspection. The inspection shall be performed on flight like hardware. The verification shall be considered successful when the inspection shows temperature display step sizes of 1°C (1.8°F). [HS3116V]

4.2.3.4.4 Set-Point Error

The increments of set points for temperature control shall be verified by analysis supported by test. The test shall include the measurements of temperature during operation of an integrated vehicle system at various temperatures. The verification shall be considered successful when the test shows the temperature can be controlled to +/- 1°C (1.8°F) of the set temperature within the ranges defined in HS3036. [HS3054V]

Rationale: No further Rationale required.

4.2.3.4.5 Seated Control

The capability of the crew to adjust the temperature set point shall be verified by demonstration. The demonstration shall show an adjustment of temperature during operation of an integrated vehicle system and shall be demonstrated by a single restrained crewmember. The verification shall be considered successful when the demonstration shows the temperature can be adjusted by a single crewmember. [HS3052V]

Rationale: No further Rationale required.

4.2.3.4.6 User Control Ventilation

The ability for the crew to adjust the ventilation direction and rate shall be verified by test. The test shall directly measure the air flow direction and rate as the control set points are varied. The test shall be performed in the flight or flight equivalent vehicle with flight software loads. The level 2 requirement may include review of requirement verification tested at lower levels. The verification shall be considered successful when the test shows that changing the ventilation set-points results in air flow changes. [HS3114V]

Rationale: No further Rationale required.

4.2.3.5 Monitoring

4.2.3.5.1 Temperature Display Step

Temperature display step sizes shall be verified by inspection. The inspection shall be performed on flight-like hardware. The verification shall be considered successful when the inspection shows temperature display step sizes of 1° C (1.8°F). [HS3115V]

Rationale: No additional rationale required.

4.2.3.5.2 Temperature/Relative Humidity Monitoring

The ability of the vehicle to measure and record temperature and relative humidity shall be verified by demonstration. The demonstration shall be performed in a flight or flight equivalent vehicle with flight software loads. The demonstration shall be considered successful when it demonstrates the vehicle's ability to correctly measure, display to the crew and record the temperature within the habitable volume. [HS3055V]

Rationale: No further Rationale required.

4.2.4 ACCELERATION

4.2.4.1 Sustained Linear Acceleration

4.2.4.1.1 Jerk

The crew exposure to jerk during sustained events shall be verified by analysis and test. Analysis shall use a certified simulation to verify all nominal flight phase scenarios, as well as 3-sigma bounding 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, parachute tests, and/or other available flight and ground-based tests. Test data provide continuous acceleration measures to compute the linear jerk that would be experienced by the crew. Such testing will require on-board acquisition (or sampling) of 3D linear acceleration (along the x, y, and z axes) on a millisecond timescale. The verification shall be considered successful when the analyses indicate with 99% confidence that the simulated jerk is no greater than 500 g/s during any non-impact phase of flight. [HS3059V]

Rationale: No further Rationale required.

4.2.4.1.2 Nominal Return

The crew exposure to sustained linear acceleration during a nominal return to earth shall be verified by analysis and test. Analysis shall use a certified simulation to verify all nominal flight phase scenarios, as well as 3-sigma bounding 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, parachute 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. The verification shall be considered successful when the analyses indicate with 99% confidence that simulated linear acceleration exposures of 500 msec or more during a nominal return are no greater than the limits depicted by the dotted green lines in Figures 3.2-1 through 3.2-5. [HS3060V]

Rationale: No further Rationale required.

4.2.4.1.3 Nominal Destination

The crew exposure to sustained linear acceleration during a nominal trip to destination shall be verified by analysis and test.

Analysis shall use a certified simulation to verify all nominal flight phase scenarios, as well as 3-sigma bounding 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, parachute 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. The verification shall be considered successful when the analyses indicate with 99% confidence that simulated linear acceleration exposures of 500 msec or more during a nominal abound trip are no greater than the limits depicted by the dashed blue lines in Figures 3.2-1 through 3.2-5. [HS3061V]

Rationale: No further Rationale required.

4.2.4.1.4 Ascent Abort and Off-Nominal Entry

The crew exposure to sustained linear acceleration during ascent abort and off-nominal entry shall be verified by analysis and test.

Analysis shall use a certified simulation to verify nominal ascent-abort and off-nominal entry scenarios, as well as 3-sigma bounding 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, parachute 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. The verification shall be considered successful when the analyses indicate with 99% confidence that simulated linear acceleration exposures of 500 msec or more during ascent abort and off-nominal entry are no greater than the limits depicted by the solid red lines in Figures 3.2-1 through 3.2-5. [HS3062V]

Rationale: No further Rationale required.

4.2.4.2 Transient Linear Acceleration

4.2.4.2.1 Transient Linear Accelerations

The crew exposure to impact acceleration shall be verified by analysis and test.

Analysis shall use a certified simulation to verify all nominal flight scenarios, as well as 3-sigma bounding 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, ascent abort tests, parachute tests, landing attenuation 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. The verification shall be considered successful when the analyses indicate with 99% confidence that the beta index is 1 or less during any simulated impact. [HS3064V]

Rationale: No further Rationale required.

4.2.4.3 Rotational Acceleration

4.2.4.3.1 Sustained Rotational Acceleration

The crew exposure to sustained rotational acceleration shall be verified by analysis and test.

The test shall consist of flight tests. In addition nominal flight tests, ascent abort tests, parachute tests, and landing attenuation tests will provide acceleration measures to evaluate vehicle rotational acceleration. Testing will require continuous on-board acquisition (or sampling) of 3D rotational acceleration (yaw, pitch, and roll) on a millisecond timescale. The analysis shall use a certified simulation to verify all nominal flight phase scenarios.

The verification shall be considered successful 1) when the tests indicate that the measured sustained rotational acceleration is no greater than 115 degrees/s2 for all tests and 2) the analyses indicate that the expected sustained rotational acceleration does not exceed 115 degrees/s2. [HS3065V]

Rationale: No further Rationale required.

4.2.4.3.2 Transient Rotational Acceleration

The crew exposure to transient rotational acceleration shall be verified by analysis and test. The test shall consist of flight tests. In addition nominal flight tests, ascent abort tests, parachute tests, and landing attenuation tests will provide acceleration measures to evaluate vehicle rotational acceleration. Testing will require continuous on-board acquisition (or sampling) of 3D rotational acceleration (yaw, pitch, and roll) on a millesecond timescale. The analysis shall use a certified simulation to verify all nominal flight phase scenarios. The verification shall be considered successful 1) when the tests indicate that the measured rotational acceleration is no greater than (TBD-006-052) degrees/s2 for all tests and 2) the analyses indicate that the expected rotational acceleration does not exceed (TBD-006-052) degrees/s2. [HS3065AV]

Rationale: No further Rationale required.

4.2.4.4 Rotational Rates

4.2.4.4.1 Nominal Return

The crew exposure to rotation shall be verified by analysis and test.

The test shall consist of flight tests. Nominal flight tests, ascent abort tests, parachute tests, and landing attenuation tests will provide acceleration measures to evaluate vehicle rotational acceleration. Testing will require continuous on-board acquisition (or sampling) of 3D rotational rate at least every 100 msec. The analysis shall use a certified simulation to verify all nominal flight phase scenarios, as well as 3-sigma bounding Monte Carlo studies with dispersed GN&C, vehicle and environmental factors.

The verification shall be considered successful 1) when the tests indicate that the measured rotation rate is no greater than the limits in those depicted in Figures 3.2.4-6 for all tests and 2) the analyses indicate with 99% confidence that the simulated rotation rate is no greater than these same limits. [HS3069V]

Rationale: No further Rationale required.

4.2.4.4.2 Nominal Destination

The crew exposure to rotation shall be verified by analysis and test.

The test shall consist of flight tests. Nominal flight tests, ascent abort tests, parachute tests, and landing attenuation tests will provide acceleration measures to evaluate vehicle rotational acceleration. Testing will require continuous on-board acquisition (or sampling) of 3D rotational rate at least every 100 msec. The analysis shall use a certified simulation to verify all nominal flight phase scenarios, as well as 3-sigma bounding Monte Carlo studies with dispersed GN&C, vehicle and environmental factors.

The verification shall be considered successful 1) when the tests indicate that the measured rotation rate is no greater than the limits in those depicted in Figures 3.2-6 for all tests and 2) the analyses indicate with 99% confidence that the simulated rotation rate is no greater than these same limits. [HS3070V]

Rationale: No further Rationale required.

4.2.4.4.3 Ascent Abort and Off-Nominal Entry

The crew exposure to rotation shall be verified by analysis and test.

The test shall consist of flight tests. Nominal flight tests, ascent abort tests, parachute tests, and landing attenuation tests will provide acceleration measures to evaluate vehicle rotational acceleration. Testing will require continuous on-board acquisition (or sampling) of 3D rotational rate at least every 100 msec. The analysis shall use a certified simulation to verify all nominal flight phase scenarios, as well as 3-sigma bounding Monte Carlo studies with dispersed GN&C, vehicle and environmental factors.

The verification shall be considered successful 1) when the tests indicate that the measured rotation rate is no greater than the limits in those depicted in Figures 3.2-6 for all tests and 2) the analyses indicate with 99% confidence that the simulated rotation rate is no greater than these same limits. [HS3071V]

Rationale: No further Rationale required.

4.2.5 VIBRATION

4.2.5.1 Health Limits

The vibration health and safety limit shall be verified by analysis and test. The analysis shall consist of a simulation of the vibration levels at the crew-vehicle physical interfaces. In accordance with ISO 2631-1:1997(E), vibration components in directions tangential to the supporting surfaces shall be multiplied by a factor of k = 1.4, while those in the direction normal shall not be rescaled (k = 1). No other ISO 2631-1 weightings shall be applied to these vibration components. Test data shall be used to support validation of the model, obtained from ground vibration testing and/or flight tests, parachute tests, and/or entry tests to provide acceleration measurements to evaluate vehicle vibration under all dynamic phases of flight. Testing will require on-board acquisition (or sampling) of 3D linear acceleration (along the x, y, and z axes) on a millisecond timescale to determine the vibration profile. The verification shall be successful when the simulated vibration level at the crew-vehicle interfaces in any arbitrary axis does not exceed 0.6 g rms integrated from 0.0167 to 80 Hz over any 1-minute interval during simulation of the dynamic phases of the mission. [HS3105V]

Rationale: 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. 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 flight test data is required to understand what the crew will experience, and to provide data for additional analyses given the possibility that the flight test vehicle will not be completely like the actual flight vehicle. Because of safety concerns in M.J. Griffin' "Handbook of Human Vibration," pp. 200-201 about higher-frequency vibrations for high amplitude and short exposure, only the unweighted vibration accelerations shall be used in this verification (i.e., do not use Wk and Wd weightings from ISO 2631-1).

4.2.5.2 Crew Sleep

The sustained baseline vibration limit requirement shall be verified by test and analysis. The test shall consist of flight tests to obtain flight vibration profiles of the vehicle's crew compartment after orbital insertion. Testing will require continuous on-board acquisition (or sampling) of 3D linear acceleration (along the x, y, and z axes) on a millisecond timescale to determine the vibration profile. The recorded test profile shall then drive an analytic simulation of crew compartment vibrations. The analysis shall identify all hardware components that contribute to the vibration environment, when they will be in their vibrating state, and the estimated contribution of each to the total vibration environment. The analysis shall combine the vibration levels of all components to estimate the total vibration at the crew-vehicle interfaces in the rest areas. Frequency-based weightings in accordance with ISO 2631-1:1997(E) shall be applied to vibration components at the crew-vehicle interface in the rest areas. The verification shall be considered successful when the analysis shows that the simulated vibration levels at the crew-vehicle interfaces in rest areas during sleep periods averaged over an 8-hour sleep period do not exceed 0.01 g rms integrated from 0.0167 to 80 Hz. [HS3106V]

Rationale: Since 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 on individual hardware components using available flight test data and to combine their levels into an integrated vibration environment.

4.2.5.3 Intermittent

The intermittent vibration limit shall be verified by test and analysis. The test shall consist of flight tests to obtain flight vibration profiles of the vehicle's crew compartment after orbital insertion. Testing will require continuous on-board acquisition (or sampling) of 3D linear acceleration (along the x, y, and z axes) on a millisecond timescale to determine the vibration profile. The recorded test profile shall then drive an analytic simulation of crew compartment vibrations. The analysis shall identify all hardware components that contribute to the vibration environment, when they will be in their vibrating state, and the estimated contribution of each to the total vibration environment. The analysis shall combine the vibration levels of all components to estimate the total vibration at the crew-vehicle interfaces in the rest areas. Frequency-based weightings in accordance with ISO 2631-1:1997(E) shall be applied to vibration components at the crew-vehicle interface in the rest areas. The verification shall be considered successful when the analysis shows that the simulated vibration levels at the crew-vehicle interfaces in rest areas during sleep periods averaged over any 1-minute interval during sleep periods do not exceed 0.09 g rms integrated from 0.0167 to 80 Hz. [HS3107V]

Rationale: Since 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 on individual hardware components using available flight test data and to combine their levels into an integrated vibration environment.

4.2.5.4 Pre-Launch, Motion Sickness

The pre-launch vibration limit shall be verified by test and analysis. The test shall consist of a flight test to obtain the vibration profile of the vehicle's crew compartment on the pad prior to launch. Testing will require continuous on-board acquisition (or sampling) of 3D linear acceleration (along the x, y, and z axes) on a millisecond timescale to determine the vibration profile. The recorded test profile shall then drive an analytic simulation of crew compartment vibrations. The analysis shall consist of a simulation of the vibration levels at the crew-vehicle physical interfaces. The verification shall be successful when the simulated vibration level at the crew-vehicle interfaces in any axis do not exceed 0.05 g rms integrated from 0.1 to 0.63 Hz over any 10-minute interval during simulation of the pre-launch phase. [HS3108V]

Rationale: The vibration levels that reach the crew are the result of several factors provided by the launch vehicle, the crew vehicle, connecting structure, and natural environment. The resultant vibration levels may be too complex to be determined from analysis alone. In order to determine if the vehicle has met the pre-launch vibration limit, actual flight test data is *required to understand what the crew will experience, and to provide data for additional analyses given the possibility that the flight test vehicle will not be completely like the actual flight vehicle.*

4.2.6 ACOUSTICS

4.2.6.1 Launch, Entry and Burn Phases

4.2.6.1.1 Noise Dose Limits

The Launch and Entry Phases – Noise Dose Limits shall be verified by test and analysis. The noise level as a function of time for the launch, entry or burn phase 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 crew-member'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. The verification shall be considered successful when tests and analysis indicate that the 24-hour noise dose associated with launch, entry and burn phases predicted at the crewmember's ears is 100% or less. [HS3073V]

Rationale: No further Rationale required.

4.2.6.1.2 Impulse Noise

The Launch and Entry Phases - Impulse Noise limit 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 crew-member'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 having peak overall SPLs of less than 110 dB. 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. [HS3074V]

Rationale: Significant noise sources consist of pyrotechnics, rocket ignition, and any other impulse noise source potentially greater than 110 dB SPL.

4.2.6.1.3 Hazardous Noise Limit

The Launch and Entry Phases - Hazardous 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 crew-member'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, during launch, entry and burn phases, the maximum level predicted at the crewmember's ears is 105 dBA or less. [HS3072V]

Rationale: No further Rationale required.

4.2.6.2 Orbit Phase

4.2.6.2.1 Impulse Noise

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 having 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. [HS3078V]

Rationale: 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.

4.2.6.2.2 Impulse Annoyance Noise

The Impulse Annoyance Noise limit shall be verified by Test. The measurements shall be made within the vehicle in the flight configuration with integrated GFE, Portable Equipment, Payloads, and Cargo installed. Hardware shall be operated at settings that occur during crew rest periods. Measurements shall be made, using a Type 1 integrating-averaging sound level meter, at expected sleep station head locations. Measurement locations shall be no closer than 8 cm from any surface. Peak-hold sound pressure level measurements (impulse noise) shall be made. The verification shall be considered successful when measurements show that the peak overall sound pressure levels are less than 83 dB. [HS3079V]

Rationale: 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.

4.2.6.2.3 Hazardous Noise Limit

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) indicate 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 (LA,max), for any combination of individual hardware items that may occur simultaneously. [HS3075V]

Rationale: 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.

4.2.6.2.4 Sound Pressure Level (SPL) Limits - Continuous Noise

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:

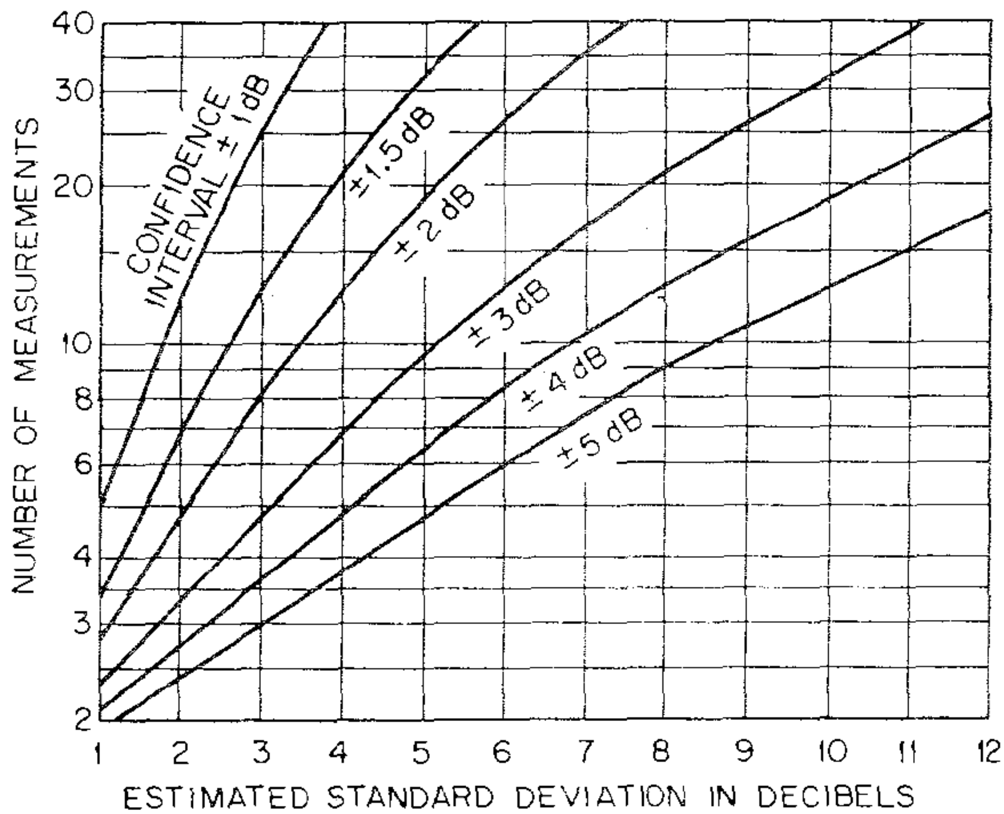
1) the measured Leq at each expected work and sleep station head location, and the estimated center of the habitable volume does not exceed the levels within each octave band indicated in Table 3.2-7;

2) the spatially-averaged SPLs (average of pressure-squared values) throughout the habitable volume do not exceed the levels given in Table 3.2-7. 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 (see Figure 4.2-1); and

3) 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 3.2-7 at the corresponding octave-band center frequency. [HS3076V]

Rationale: Lower nominal settings of major hardware components shall also be tested and documented since 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.

Figure 4.2-1 Number of measurements vs, standard deviation to determine a ± 2 dB 90% confidence interval (from "Acoustical Measurements and Noise Control" by C. M. Harris, p. 9.9, Figure 9.7)

4.2.6.2.5 Sound Pressure Level (SPL) Limits - Intermittent Noise

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 of equipment indicated in Table 3.2-8. 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 Table 3.2-7. This verification shall be considered successful when the test (and any performed simulations) indicate that the maximum noise level for the duration of intermittent operation, measured 0.6 m from the loudest point on the hardware surface, meet the level and duration limits specified in Table 3.2-9. [HS3109V]

Rationale: 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.

4.2.6.3 All Flight Phases

4.2.6.3.1 Tonal and Narrow-Band Noise Limits

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 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. Tonal and narrow-band component measurements shall also be made using an Fast Fourier Transform (FFT) with a frequency resolution of 1 Hz. Measurements shall be made at expected work and sleep station head locations. 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 sleep station head locations is at least 10 dB less than the broadband SPL of the octave band that contains the component or tone for the 1, 2, 4, and 8 kHz octave bands, and at least 5 dB less than the broadband SPL of the octave band that contains the component or tone for the 63, 125, 250 and 500 Hz octave bands, at the same location. [HS3080V]

Rationale: No further Rationale required.

4.2.6.3.2 Cabin Depressurization Valve Hazardous Noise Limit

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 crew-member's ear by combining significant noise sources from estimates of valve noise, and include 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. 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. [HS3082V]

Rationale: No further Rationale required.

4.2.6.3.3 Cabin Depressurization Valve Noise Dose Limits

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 crew-member's ear by combining significant noise sources from estimates of valve noise, and include 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. The verification shall be considered successful when tests and analysis indicate that the 24-hour noise dose, associated with pressure valve releases, predicted at the crewmember's ears is 100% or less. [HS3083V]

Rationale: No further Rationale required.

4.2.6.3.4 Reverberation Time

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. Reverberation time shall be determined from the reverse-integrated decay curve, with a straight line fit made from -5 dB below the direct sound arrival to -20 dB. The test and analysis shall be considered successful when the determined time required for sound to decay from -5 to -20 dB is less than 0.6 seconds within the 500 Hz, 1 kHz, and 2 kHz octave bands. [HS3084V]

Rationale: 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.

4.2.6.3.5 Headsets

The headset 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. The verification shall be considered successful when the test shows that the measured maximum SPL at the crew member's ear is 115 dBA or less. [HS3110V]

Rationale: No further Rationale required.

4.2.6.3.6 Loudspeaker Alarm Audibility

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).

Sound pressure measurements shall be made within each one-third-octave band with center frequencies ranging from 300 Hz to 3 kHz, using a Type 1 integrating-averaging sound level meter using a peak hold function with a fast (125 ms) exponentially-weighted time averaged response. Measurements shall be made at expected work and sleep station head locations. The ambient noise level shall be measured via a 20 second Leq (slow time weighting). The verification shall be considered successful when the test indicates that, for each temporal component of the annunciation, the level in at least one one-third-octave band is more than 13 dB above the ambient noise level, at each expected work and sleep station location. [HS3111V]

Rationale: No further Rationale required.

4.2.6.3.7 Infrasonic Noise Limits

(TBR-006-022).

4.2.7 IONIZING RADIATION

4.2.7.1 Radiation Design Requirements

4.2.7.1.1 Radiation Design Requirements

Radiation exposure shall be verified by analysis. The analysis shall be performed through the use of a model with the following components: Design Environment: CxP 70023, Constellation Design Specification for Natural Environments (DSNE), Section 3.3.4. Transport code: The HZETRN_2005 code provided as GFE by CxP. Vehicle Geometry: CFE CxP standard CAD (Computer Aided Drafting) model of the vehicle structure, hardware, stowage, and CFE equipment. This includes materials specification sufficient to derive chemical composition and bulk density for each instance/part in the design. The vehicle as analyzed shall be representative of a standard lunar transit configuration for vehicle components, equipment and stowage items as well as a minimum crew complement placed within the habitable volume. Shield Evaluation / Mass Distribution Evaluation: Barrier Thickness Evaluator (BTE) code provided as GFE by CxP.

Human Geometry: 50th percentile Computerized Anatomical Female (CAF) model provided as GFE by CxP. Analysis locations within the human body and mass distribution solid angle distributions also provided for analysis as GFE by CxP.

The verification shall be considered successful when the analysis shows that the maximum effective dose incurred by any crew-member within the vehicle does not exceed 150 mSv for the design SPE, as specified in CxP-70023.

$$E = \sum_T w_T H_T$$

Effective dose shall be calculated as a quantity,

where the equivalent dose, H_T, is defined as $H_T = Q(L) D_{T,R}$

$D_{T,R}$ is the dose averaged over a specific organ or tissue (T) due to radiation (R).
The tissue weighting factor ω_T is given in Table 4.3, for required tissues/organs, in National Council on Radiation Protection and Measurements (NCRP) report number 132.
Q(L) is the radiation quality factor as a function of same as specified in National Council on Radiation Protection and Measurements (NCRP) report number 132, Table 4.2 Q vs. L relationship, Radiation Protection Guidance for Activities in Low-Earth Orbit. [HS3085V]

Rationale: 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.

4.2.7.2 Active Radiation Monitoring

4.2.7.2.1 Charged Particle Monitoring

Charged particle monitoring shall be verified by test and analysis for detector integration into the vehicle. The test shall use 1 flight equivalent instrument to verify the requirement the test shall use accelerator sources of charged of particles with Z =1, 2, 6, 8, 14, and 26. The test shall use two energies within 30 to 300 MeV/nucleon for Z<3. The test shall use two energies within 100 to 400 MeV/nucleon for $3 \leq Z \leq 26$. The test shall use a total fluence of not less than 100,000 cm-2 delivered at a fluence rate range 500 cm-2 s-1 to 1000 cm-2 s-1 for 2<Z<26 and a total fluence of 100,000 cm-2 delivered at a fluence rate no smaller than 2000 cm-2 s-1 for Z =1. The analysis shall use a geometrical assessment of the CAD (Computer Aided Drafting) vehicle model to verify the unobstructed viewing angle requirement. The verification shall be considered successful when the test shows agreement with reference fluence within +- 10%, with an energy resolution <30% and when the analysis shows an unobstructed viewing angle not less than 1.1345 Radians (65 degrees) (TBR-006-023) . [HS3086V]

Rationale: Test is the necessary method for verification of this requirement. The verification cannot be performed for all components of the space radiation field in which the vehicle will be exposed. The selected test fields span the range of the Z, energy, linear energy transfer, fluences, and fluence rates expected during the missions.

4.2.7.2.2 Dose Equivalent Monitoring

Dose equivalent monitoring shall be verified by test. The test shall use 1 flight equivalent instrument to verify the requirement. The test shall be an exposure of the flight equivalent instrument to radiation sources. The test shall use accelerator sources of charged of particles with Z =1, 6, and 26. The test shall use Cesium-137 or Cobalt-60 photon source. Each radiation source shall deliver use total dose equivalent of 10 mSv for each of the dose equivalent ranges of: 0.5 mSv per hour to 3 mSv per hour and 5 mSv per hour to 10 mSv per hour. The verification shall be considered successful when the test shows +- 20% agreement between the measured and reference dose equivalent rate and total dose equivalent. [HS3088V]

Rationale: Test is the necessary method for verification of this requirement. Instrument operation cannot be simulated or inspected. Exposure to actual radiation fields is required to verify instrument is operational and meets design specifications. The verification cannot be performed for all components of the space radiation field in which the vehicle will be exposed. The selected test fields span the range of the Z, energy, linear energy transfer, dose equivalents, and dose equivalent rates expected during the missions, including radiation fields expected during solar particle events.

4.2.7.2.3 Absorbed Dose Monitoring

Absorbed dose monitoring shall be verified by test. The test shall use 1 flight equivalent instrument to verify the requirement. The test shall be an exposure of the flight equivalent instrument to radiation sources. The test shall use accelerator sources of charged of particles with Z =1, 6, and 26. Each radiation source shall deliver use total dose of 10 mGy for each of the dose equivalent ranges of: 0.5 mGy per hour to 3 mGy per hour and 5 mGy per hour to 10 mGy per hour. The verification shall be considered successful when the test shows +- 20% agreement between the measured and reference dose rate and total dose. [HS3089V]

Rationale: Test is the necessary method for verification of this requirement. Instrument operation cannot be simulated or inspected. Exposure to actual radiation fields is required to verify instrument is operational and meets design specifications. The verification cannot be performed for all components of the space radiation field in which the vehicle will be exposed. The selected test fields span the range of the Z, energy, linear energy transfer, absorbed doses, and absorbed dose rates expected during the missions, including radiation fields expected during solar particle events.

4.2.7.3 Passive Radiation Monitoring

4.2.7.3.1 Passive Radiation Monitoring Attach Points

The attach points for passive radiation detectors shall be verified by inspection. The inspection shall be visual inspection of the attach location points specified in the Portable Equipment IRD. The verification shall be considered successful when the inspection confirms that 6 detector attach points are located at the locations specified in the Portable Equipment IRD. [HS3090V]

Rationale: 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 attach points will be based on the projected radiation exposures, using transport calculation and vehicle geometry, within the vehicle given in DRD T-045.

4.2.7.4 Reporting

4.2.7.4.1 Crew Reporting

The absorbed dose measurement reporting shall be verified by test.

-the test shall use 1 flight equivalent instrument to take the measurements -the test shall use the vehicle data management system or equivalent to receive the measurements -the test will be a simulated operational session of measurements taken by the flight equivalent instrument interfaced to the data management system or equivalent -the test shall be a 1 hour measurement -the test shall be considered successful when the data reported to the vehicle data management system or equivalent is updated every 1 minute and the time tag on the data reported is less than 5 minutes older than actual time when the data was recorded. [HS3091V]

Rationale: Test is the necessary method for verification of this requirement. The instrument interface to the data management system or equivalent must be tested with the actual hardware to ensure the instrument is passing that can be reported correctly.

4.2.7.4.2 Mission Systems Reporting

The absorbed dose measurement reporting shall be verified by test.

-the test shall use 1 flight equivalent instrument to take the measurements -the test shall use the vehicle data management system or equivalent to receive the measurements -the test shall use Mission operations or equivalent -the test will be a simulated operational session of measurements taken by the flight equivalent instrument interfaced to the data management system or equivalent and Mission operations or equivalent. -the test shall be a 4 hour measurement and transmission -the test shall be considered successful when the received data is updated every minute, time tag on data received is less 5 minutes older than actual time, when the data received is transmitted [HS3112V]

Rationale: Test is the necessary method for verification of this requirement. The instrument interface to the data management system or equivalent and Mission Systems must be tested with the actual hardware to ensure the instrument is passing data that can be reported correctly.

4.2.7.4.3 Particle Archive Data

Data archival shall be shall be verified by test and analysis.

The test shall use each flight equivalent instrument used to make charged particle, dose equivalent, absorbed dose, measurements -the test shall use the vehicle data management system or equivalent to receive the measurements -the test shall use Mission Operations or equivalent -the test will be a simulated operational session of measurements taken and recorded by the flight equivalent instruments interfaced to the data management system or equivalent and Mission Operations or equivalent. -the test shall be a 1 day measurement and subsequent transmission of archival data. -the test shall be considered successful when the data received by Mission Operations is confirmed to be identical to the recorded data. -the analysis shall use a data set from each of the flight equivalent instruments equivalent to the data generated during flight operation. -the analysis shall be considered successful when the total memory allocation for each flight equivalent instrument is shown to be larger than the mission data set size of the longest design reference mission. [HS3113V]

Rationale: Test is the necessary method for verification of this requirement. The instrument interface to the data management system or equivalent and Mission Systems must be tested with the actual hardware to ensure the instrument is passing archive data can be that can downlinked correctly. The integrity of the real acquired data must be confirmed to ensure that data corruption is not occurring during the downlink.

4.2.7.5 Alerting

4.2.7.5.1 Alerting

The absorbed dose alerting shall be verified by demonstration

The demonstration shall consist of setting thresholds at 0.02 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 3 consecutive readings.

Tthe 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. [HS3092V]

Rationale: 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 crew members during high dose rate conditions. The alarm testing does not require analysis, but will verify an alarm or no alarm condition.

4.2.8 NON-IONIZING RADIATION

4.2.8.1 Radio-Frequency Radiation Limits

4.2.8.1.1 Radio-Frequency Electromagnetic Field Radiation Limits

Crew exposure to radio-frequency electromagnetic fields shall be verified by analysis. Data generated in response to the Cx E3 verification test requirements (Constellation E3 Requirements Document) 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. The verification shall be considered successful when the analysis shows crew exposures are within the limits specified in Appendix C Table C-3 and Figure C-3. [HS3093V]

Rationale: The test which provides the data for this verification analysis is the same type of testing which is normally performed to determine EM field effects with regard to avionics hardware. Analysis must be performed using this test data to synthesize the exact characteristics of each individual field produced, as well as the combined EM field environment, with regard to exposure levels for the crew. NOTE: Drive EMI Team to do assessments for humans in addition to the equipment.

4.2.8.2 Laser Radiation Limits

4.2.8.2.1 Point Sources

Ocular exposure from Class 3b and 4 point source laser systems shall be verified by analysis. The analysis shall be performed as defined by ANSI Z136.1. The verification shall be considered successful when the analysis shows ocular exposure is within the limits in Appendix C Table C-4 without protective equipment. [HS3094V]

Rationale: Analysis must be used to verify this requirement. To prove that the ANSI standard is met, the laser system must be analyzed with regard to its operating parameters, operational configuration, isolation and containment measures. Protective equipment as defined by the ANSI standard is, "...protection in the form of goggles or spectacles, barriers, windows, clothing and gloves, and other devices which have been specifically selected for suitable protection against laser radiation." (pg 39, section 4.6.1)

4.2.8.2.2 Extended Sources

Ocular exposure from Class 3b and 4 extended source laser systems shall be verified by analysis. The analysis shall be performed as defined by ANSI Z136.1. The verification shall be considered successful when the analysis shows ocular exposure is within the limits in Appendix C Table C-5 without protective equipment. [HS3095V]

Rationale: Analysis must be used to verify this requirement. To prove that the ANSI standard is met, the laser system must be analyzed with regard to its operating parameters, operational configuration, isolation and containment measures. Protective equipment as defined by the ANSI standard is, "protection in the form of goggles or spectacles, barriers, windows, clothing and gloves, and other devices which have been specifically selected for suitable protection against laser radiation." (pg 39, section 4.6.1)

4.2.8.2.3 Skin Exposure

Skin exposure from Class 3B and 4 laser systems shall be verified by analysis. The analysis shall be performed as defined by ANSI Z136.1. The verification shall be considered successful when the analysis shows ocular exposure is within the limits in Appendix C Table C-6 without protective equipment. [HS3096V]

Rationale: Analysis must be used to verify this requirement. To prove that the ANSI standard is met, the laser system must be analyzed with regard to its operating parameters, operational configuration, isolation and containment measures. Protective equipment as defined by the ANSI standard is, "protection in the form of goggles or spectacles, barriers, windows, clothing and gloves, and other devices which have been specifically selected for suitable protection against laser radiation." (pg 39, section 4.6.1)

4.2.8.2.4 Selected Continuous-Wave Lasers

Eye and skin exposure from laser systems specified in Appendix C Table C-7 shall be verified by analysis. The analysis shall be performed as defined by ANSI Z136.1. The verification shall be considered successful when the analysis shows eye and skin exposure are within the limits in Appendix C Table C-7 without protective equipment. [HS3097V]

Rationale: Analysis must be used to verify this requirement. To prove that the ANSI standard is met, the laser system must be analyzed with regard to its operating parameters, operational configuration, isolation and containment measures. Protective equipment as defined by the ANSI standard is, "protection in the form of goggles or spectacles, barriers, windows, clothing and gloves, and other devices which have been specifically selected for suitable protection against laser radiation." (pg 39, section 4.6.1)

4.2.8.3 Incoherent Radiation

4.2.8.3.1 Retinal Thermal Injury from Visible and Near Infrared Light

4.2.8.3.1.1 Internal Spectral Radiance Limits

Window transmittance shall be verified by test. Witness Samples of the actual flight windows in flight configuration shall have their transmittance values measured in 5 nm increments between 385 nm and 1400 nm. The test report shall be provided to NASA including the transmittance data and a graphical representation of the transmittance data. The verification shall be considered successful when the test shows that the limits calculated from the equation in this requirement are maintained throughout the applicable spectrum (385-1400nm). [HS3098V]

Rationale: A test is required for the system, specifically to scale in the flight configuration. The verification cannot be performed for each component and then analyzed using the component data, since the addition of each component does not result in a strictly additive effect. Each required product specified as resulting from the testing is necessary for verification of this requirement as well as other requirements in this section. Witness sample is a portion of material that is processed at the same time and under the same conditions as the end item product.

4.2.8.3.1.2 Lighting Sources Internal Spectral Radiance Limits

Spectral radiance for light sources exceeding (TBD-006-001) radiance shall be verified by test. Spectral radiation shall be measured in 5 nm increments between 385 and 1400 nm. The test report shall be provided to NASA including the radiance data and a graphical representation of the radiance data. The verification shall be considered successful when the test shows that the limits calculated from the equation in this requirement are maintained throughout the applicable spectrum (385-1400nm). [HS3098AV]

Rationale: Test is the necessary method for verification of this requirement, as over this specified range, several different damage mechanisms come into play. A full spectral test is required, in the defined increments, to assure that the equipment under test does not exhibit localized resonance ("spikes") in radiance. Each required product specified as resulting from the testing is necessary for verification of this requirement as well as other requirements in this section.

4.2.8.3.2 Retinal Photochemical Injury from Visible Light

4.2.8.3.2.1 Small Sources

Window transmittance shall be verified by test. Witness Samples of the actual Flight Windows in normal flight configuration shall have their transmittance values measured in 5 nm increments between 305 nm and 700 nm. The test report shall be provided to NASA including the transmittance data and a graphical representation of the transmittance data. The verification shall be considered successful when the test shows that the limits calculated from the equations in this requirement are maintained throughout the applicable spectrum (305-700nm). [HS3099V]

Rationale: Test is the necessary method for verification of this requirement, as over the 305 to 700 nanometer range, several different damage mechanisms come into play. A full spectral test is required, in 5 nanometer increments, to assure that the equipment under test does not exhibit localized resonance ("spikes") in transmission. Each required product specified as *resulting from the testing is necessary for verification of this requirement as well as other requirements in this section.*

4.2.8.3.2.2 Spectral Irradiance-Small Sources

Internal spectral radiance for light sources in excess of (TBD-006-002) shall be verified by test. Spectral radiation shall be measured in 5 nm increments between 305 and 700 nm. The test report shall be provided to NASA including the radiance data and a graphical representation of the radiance data. The verification shall be considered successful when the test shows that the limits calculated from the equations in this requirement are maintained throughout the applicable spectrum (305-700 nm). [HS3099AV]

Rationale: Test is the necessary method for verification of this requirement, as over the 305 to 700 nanometer range, several different damage mechanisms come into play. A full spectral test is required, in 5 nanometer increments, to assure that the equipment under test does not exhibit localized resonance ("spikes") in radiance. Each required product specified as resulting from the testing is necessary for verification of this requirement as well as other requirements in this section.

4.2.8.3.2.3 Large Sources

Window transmittance shall be verified by test. Witness Samples of the actual Flight Windows in normal flight configuration shall have their transmittance values measured in 5 nm increments between 305 nm and 700 nm. The test report shall be provided to NASA including the transmittance data and a graphical representation of the transmittance data. The verification shall be considered successful when the test shows that the limits calculated from the equations in this requirement are maintained throughout the applicable spectrum (305-700nm). [HS3101V]

Rationale: Test is the necessary method for verification of this requirement, as over the 305 to 700 nanometer range, several different damage mechanisms come into play. A full spectral test is required, in 5 nanometer increments, to assure that the equipment under test does not exhibit localized resonance ("spikes") in transmission. Each required product specified as resulting from the testing is necessary for verification of this requirement as well as other requirements in this section. Witness sample is a portion of material that is processed at the same time and under the same conditions as the end item product.

4.2.8.3.2.4 Spectral Irradiance-Large Sources

Spectral radiance shall be verified by test for those light sources exceeding (TBD-006-003) radiance. Spectral radiation shall be measured in 5 nm increments between 305 and 700 nm. The test report shall be provided to NASA including the radiance data and a graphical representation of the radiance data. The verification shall be considered successful when the test shows that the limits calculated from the equations in this requirement are maintained throughout the applicable spectrum (305-700nm). [HS3101AV]

Rationale: Test is the necessary method for verification of this requirement, as over the 305 to 700 nanometer range, several different damage mechanisms come into play. A full spectral test is required, in 5 nanometer increments, to assure that the equipment under test does not exhibit localized resonance ("spikes") in radiance. Each required product specified as *resulting from the testing is necessary for verification of this requirement as well as other requirements in this section.*

4.2.8.3.3 Thermal Injury from Infrared Radiation

4.2.8.3.3.1 Internal Infrared Radiation Limits

Window transmittance shall be verified by test. Witness Samples of the actual Flight Windows in normal flight configuration will have their transmittance values measured in 5 nm increments between 770 nm and 3000 nm. The test report shall be provided to NASA including the transmittance data and a graphical representation of the transmittance data. The verification shall be considered successful when the test shows that the limits calculated from the equation in this requirement are maintained throughout the applicable spectrum (770-3000nm). [HS3103V]

Rationale: Test is the necessary method for verification of this requirement, as over the 770 to 3000 nanometer range, several different damage mechanisms come into play. A full spectral test is required, in 5 nanometer increments, to assure that the equipment under test does not exhibit localized resonance ("spikes") in transmission. Each required product specified as resulting from the testing is necessary for verification of this requirement as well as other requirements in this section. Witness sample is a portion of material that is processed at the same time and under the same conditions as the end item product.

4.2.8.3.3.2 Light Sources Infrared Radiation Limits

Spectral radiance shall be verified by test for those light sources exceeding (TBD-006-021) radiance. Spectral radiation shall be measured in 5 nm increments between 770 and 3000 nm. The test report shall be provided to NASA including the radiance data and a graphical representation of the radiance data. The verification shall be considered successful when the test shows that the limits calculated from the equation in this requirement are maintained throughout the applicable spectrum (770-3000nm). [HS3103AV]

Rationale: Test is the necessary method for verification of this requirement, as over the 770 to 3000 nanometer range, several different damage mechanisms come into play. A full spectral test is required, in 5 nanometer increments, to assure that the equipment under test does not exhibit localized resonance ("spikes") in radiance. Each required product specified as resulting from the testing is necessary for verification of this requirement as well as other requirements in this section.

4.2.8.3.4 Ultraviolet Exposure for Unprotected Eye or Skin

4.2.8.3.4.1 Internal Spectral Irradiance Limits

Window transmittance shall be verified by test. Witness Samples of the actual Flight Windows in normal flight configuration will have their transmittance values measured in 5 nm increments between 180 nm and 400 nm. The test report shall be provided to NASA including the transmittance data and a graphical representation of the transmittance data. The verification shall be considered successful when the test shows that the limits calculated from the equation in this requirement are maintained throughout the applicable spectrum (180-400nm). [HS3104V]

Rationale: Test is the necessary method for verification of this requirement, as over the 180 to 400 nanometer range, several different damage mechanisms come into play. A full spectral test is required, in 5 nanometer increments, to assure that the equipment under test does *not exhibit localized resonance ("spikes") in transmission. Each required product specified as resulting from the testing is necessary for verification of this requirement as well as other requirements in this section. Witness sample is a portion of material that is processed at the same time and under the same conditions as the end item product.*

4.2.8.3.4.2 Ultraviolet Light Source Limits

Spectral radiance shall be verified by test for those light sources exceeding (TBD-006-005) radiance. Spectral radiation shall be measured in 5 nm increments between 180 and 400 nm. The test report shall be provided to NASA including the radiance data and a graphical representation of the radiance data. The verification shall be considered successful when the test shows that the limits calculated from the equation in this requirement are maintained throughout the applicable spectrum (180-400nm). [HS3104AV]

Rationale: Test is the necessary method for verification of this requirement, as over the 180 to 400 nanometer range, several different damage mechanisms come into play. A full spectral test is required, in 5 nanometer increments, to assure that the equipment under test does not exhibit localized resonance ("spikes") in radiance. Each required product specified as resulting from the testing is necessary for verification of this requirement as well as other requirements in this section.

4.3 SAFETY

4.3.1 GENERAL

4.3.1.1 Emergency Equipment Access

Emergency equipment access shall be verified by analysis. The analysis shall identify all emergency equipment that is required to address emergencies, and their location within the vehicle. The analysis shall determine the time needed to access each piece of emergency equipment per the specific emergency scenario. The verification shall be considered successful when the analysis shows that emergency equipment can be accessed within the time to address the emergency. [HS4022V]

Rationale: No further Rationale required.

4.3.2 MECHANICAL HAZARDS

4.3.2.1 Corners and Edges

Exposed corner and edge rounding shall be verified by analysis and inspection. The analysis shall determine where corners and edges to which the crew or Mission Systems personnel are to expected to be exposed during nominal operations are located. The inspection shall consist of inspection of drawings of the identified corners and edges, and physical inspection of the edges using glove or swatch cloth. The verification shall be considered successful when the analysis and inspection show that corners and edges meet the roundness specifications in Table D-1. [HS4002V]

Rationale: No further Rationale required.

4.3.2.2 Corners and Edges - Maintenance

Exposed corner and edge rounding shall be verified by analysis and inspection. The analysis shall determine where corners and edges to which the crew is to expected to be exposed during in-flight maintenance are located. The inspection shall consist of inspection of drawings of the identified corners and edges, and a sharp edge inspection. The verification shall be considered successful when the analysis and drawing inspection show that corners and edges are rounded to at least 0.01 inches and the sharp edge inspection identifies no issues. [HS4003V]

Rationale: No further Rationale required.

4.3.2.3 Loose Equipment

Loose equipment corner and edge rounding shall be verified by analysis and inspection. The analysis shall determine where corners and edges to which the crew is to expected to be exposed during in-flight maintenance are located. The inspection shall consist of a review of drawings to identify the design meets the specifications in Table D-1 and a sharp edge inspection. The verification shall be considered successful when the analysis and drawing inspection show that corners and edges are rounded to the specifications in Table D-1 and the sharp edge inspection identifies no issues. [HS4004V]

Rationale: No further Rationale required.

4.3.2.4 Burrs

Absence of burrs on surfaces shall be verified by inspection and test. The inspection shall determine where surfaces to which the crew or ground personnel are expected to be exposed during nominal operations are located. The test shall be a swatch test on all potential burrs. The verification shall be considered successful when the inspection and test show that no burrs are found on any exposed surfaces. [HS4005V]

Rationale: Inspection and test of flight hardware is necessary as burr prevention is provided through quality workmanship, and not design.

4.3.2.5 Sharp Items

Controls for sharp items shall be verified by inspection. The inspection shall identify the sharp items to which the crew or ground personnel are expected to be exposed during nominal and maintenance operations. The analysis shall identify controls for the sharp items. The verification shall be considered successful when the analysis shows that no sharp edges are found on any equipment or that sharp item controls are in place. [HS4006V]

Rationale: No further Rationale required.

4.3.2.6 Pinch Points

Control for crew exposure to pinch points shall be verified by analysis. The analysis shall identify the location of potential pinch point locations in the vehicle. The analysis shall identify controls for those pinch points that are accessible by the crew. The verification shall be considered successful when pinch points are either inaccessible to the crew or have a control to prevent injury. [HS4021V]

Rationale: No further Rationale required.

4.3.2.7 Equipment Restraints

Restraints for unstowed items shall be verified by analysis. The analysis shall identify all items that will be unstowed during any portion of the mission, and identify the restraints provided in the vehicle. The verification shall be considered successful when the analysis shows that each item that will be unstowed has a restraint mechanism. [HS4007V]

Rationale: No further Rationale required.

4.3.3 ELECTRICAL HAZARDS

4.3.3.1 Electrical Hazards Potential

Prevention of crew and Mission Systems personnel from being exposed to currents greater than those in Tables 3.3-2 and 3.3-3 shall be verified by analysis and test. The analysis shall determine the locations to which the crew may be exposed to electrical currents. The analysis shall identify controls in the locations where currents are greater than those 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 electrical current measured at each location to which the crew may be exposed is not greater than those in the tables, or that the electrical potentials controls are in place. [HS4008V]

Rationale: No further Rationale required.

4.3.3.2 Chassis Leakage Current - Non-patient Equipment

The non-patient 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 non-patient flight hardware that could come into contact with crew or ground personnel. The test shall be considered successful when the test indicates that the chassis leakage current is less than or equal to the associated limit in Figure 3.3-4. [HS4008BV]

4.3.3.3 Chassis Leakage Current - Patient Equipment

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 test shall be considered successful when the test indicates that the chassis leakage current is less than or equal to the associated limit in Figure 3.3-5. [HS4008CV]

4.3.4 TOUCH TEMPERATURES

4.3.4.1 Touch Temperature Limits

Touch temperatures shall be verified by analysis and test. The analysis shall identify all surfaces to which the crew or ground personnel are exposed and identify touch temperature controls for surfaces outside the limits defined in Table 3.3-6. The test shall measure the temperature of each surface identified in the analysis. The verification shall be considered successful when the analysis and test show that all surfaces to which the crew or ground personnel are exposed are within the limits defined in Table 3.3-6 or that touch temperature controls are in place. [HS4012V]

Rationale: No further Rationale required.

4.3.5 FIRE PROTECTION

4.3.5.1 Fire Suppression Portability

Portable fire suppression system shall be verified by inspection. The inspection shall include the review of design for the provision of a portable fire suppression system. The inspection shall also identify portable fire suppression equipment in the flight vehicle. The verification shall be considered successful when the inspection shows that the design accommodates portable fire suppression equipment and that equipment is identified in the flight vehicle. [HS4019V]

Rationale: No further Rationale required.

4.4 ARCHITECTURE

4.4.1 CONFIGURATION

4.4.1.1 Layout Interference

Not Applicable

4.4.1.2 Layout Sequential Operations

Not Applicable

4.4.1.3 Workstation Visual Demarcations

Demarcations for adjacent workstations shall be verified by inspection. The inspection shall consist of identifying adjacent workstations and identifying the demarcations between adjacent workstations. The verification shall be considered successful when the inspection shows that demarcations are identified for all adjacent workstations with vertical orientations differing by 90 degrees and greater. [HS5042V]

Rationale: No further Rationale required.

4.4.1.4 Orientation

Workstation alignment shall be verified by analysis and inspection. The analysis shall consist of determining all user-interface elements within each workstation, the expected crew head position at each workstation, and identifying the centerline for each user interface element. The inspection shall consist of measuring the orientation angle of each user-interface element as the angle between the crew head position local vertical centerline and the user-interface element local vertical centerline. The verification shall be considered successful when analysis and inspection show that all orientation angles for all user-interface elements within each workstation are measured to be 0 degrees. [HS5003V]

Rationale: No further Rationale required.

4.4.1.5 Location Coding

Use of a standard location coding system providing unique identifiers shall be verified by inspection. The inspection shall address all predefined locations within the vehicle. The verification shall be considered successful when the inspection shows that all predefined locations follow a standard location coding system. [HS7009V]

Rationale: No further Rationale required.

4.4.2 TRANSLATION PATHS

4.4.2.1 Ingress, Egress, and Escape

Translation paths shall be verified by analysis and demonstration. Analysis shall consist of performing suited operation scenarios using high fidelity computer graphic models. The models shall include the vehicle, suited crewmembers, and suited crewmembers' movement through the translation paths. The demonstration shall occur in a high-fidelity mockup in 1g in the flight configuration with integrated GFE, stowage, vehicle installations, and closeouts installed. The demonstration shall consist of suited subjects performing ingress, egress, and escape operation scenarios. The verification shall be considered successful when the analysis and demonstration show that suited ingress, egress, and escape operations can be performed without being hampered by protrusions and snag points. [HS5004V]

Rationale: No further Rationale required.

4.4.2.2 Internal

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 1g in the flight configuration with integrated GFE, stowage, vehicle installations, and closeouts installed. The demonstration shall consist of unsuited subjects performing operation scenarios. The verification shall be considered successful when the analysis and demonstration show that unsuited operations can be performed. [HS5005V]

4.4.3 RESTRAINTS AND MOBILITY AIDS

4.4.3.1 General

Not Applicable

4.4.3.2 IVA Mobility Aids

The provision of mobility aid shall be verified by inspection. Inspection shall consist of a review of engineering drawings and planned IVA operations. The verification shall be considered successful when the inspection shows that mobility aids are in locations to support IVA operations. [HS5007V]

Rationale: No further Rationale required.

4.4.3.3 Workstations

Restraint placement for two handed operations shall be verified by inspection. The inspection shall consist of a review of engineering drawings and identified locations for two handed operations. The verification shall be considered successful when the inspection shows that restraint placement allows two handed operations in 0g. [HS5008V]

Rationale: No further Rationale required.

4.4.3.4 Ingress, Egress, and Escape

Mobility aids for ingress, egress, and escape shall be verified by inspection. The inspection shall consist of a review of engineering drawings and ingress and egress translation paths. The verification shall be considered successful when the inspection shows that restraint placement allows for ingress, egress and escape. [HS5009V]

Rationale: No further Rationale required.

4.4.3.5 Crew Extraction

Assisted egress translation paths shall be verified by analysis. The analysis shall consist of demonstrating assisted egress of incapacitated suited crewmembers using high fidelity computer graphic models. The models shall include the vehicle, all suited crewmembers, and all suited crewmembers' movement through the translation paths. [HS5010V]

Rationale: No further Rationale required.

4.4.3.6 High g Environment

Prevention of flail injury shall be verified by analysis. The analysis shall identify a means of preventing flail injury for each injury as defined by NASA. The verification shall be considered successful when the analysis shows that the identified injuries have an associated means of injury prevention for restrained crewmembers. [HS5012V]

Rationale: No further Rationale required.

4.4.3.7 Commonly Distinguishable

Not applicable.

4.4.4 HATCHES

4.4.4.1 Operation

4.4.4.1.1 Nominal

4.4.4.1.1.1 Inside and Outside

Hatch operability from both sides 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 4 tasks: Unlatching and fully opening each hatch from inside; Unlatching and fully opening each hatch from outside; Closing and latching each fully-opened hatch from inside; Closing and latching each fully-opened hatch from outside. The verification shall be considered successful when the Demonstration shows that a suited subject can complete the four tasks. [HS5013V]

Rationale: No further Rationale required.

4.4.4.1.1.2 Operable in 60 Seconds

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 0g operability by performing the tasks in 1g and applying a 0g factor to the task completion time. The demonstration shall consist of one suited subject performing the following 4 tasks: Unlatching and fully opening each hatch from inside; Unlatching and fully opening each hatch from outside; Closing and latching each fully-opened hatch from inside; Closing and latching each fully-opened hatch from outside. The demonstration task completion time shall be measured in seconds. The verification shall be considered successful when the demonstration shows that the completion time is 60 seconds or less per task. [HS5043V]

Rationale: No further Rationale required.

4.4.4.1.1.3 Without Tools

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 4 tasks: Unlatching and fully opening each hatch from inside; Unlatching and fully opening each hatch from outside; Closing and latching each fully-opened hatch from inside; Closing and latching each fully-opened hatch from outside. The demonstration task completion time shall be measured in seconds. The verification shall be considered successful when demonstration shows that the hatch is operable without the use of tools. [HS5044V]

Rationale: No further Rationale required.

4.4.4.1.1.4 Suited

Hatch operability by a pressurized-suited crewmember 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 pressurized-suited subject performing the following 4 tasks: Unlatching and fully opening each hatch from inside; Unlatching and fully opening each hatch from outside; Closing and latching each fully-opened hatch from inside; Closing and latching each fully-opened hatch from outside. Verification of hatch shall be considered successful when the operability by a pressurized-suited crewmember shall be considered successful if the demonstration shows that all tasks are completed. [HS5045V]

Rationale: No further Rationale required.

4.4.4.1.1.5 Unlatching

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. The verification shall be considered successful when the demonstration shows that unlatching requires 2 distinct and sequential operations. [HS5046V]

Rationale: No further Rationale required.

4.4.4.1.2 Pressure Equalization

4.4.4.1.2.1 Inside and Outside

Manual pressure equalization on each side of the hatch by a crewmember shall be verified by demonstration. 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. The verification shall be considered successful when the demonstration shows that the procedure can be performed. [HS5014V]

Rationale: No further Rationale required.

4.4.4.1.2.2 Suited

Manual pressure equalization on each side of the hatch shall be verified by demonstration. 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. The verification shall be considered successful when the demonstration shows that a pressurized-suited crewmember can complete the procedure. [HS5048V]

Rationale: No further Rationale required.

4.4.4.2 Indications

4.4.4.2.1 Status

4.4.4.2.1.1 Latch Position

Latch position status shall be verified by demonstration. Demonstration shall occur in the vehicle or a high-fidelity mockup. Demonstration shall consist of the following tasks completed on the inside and outside of each hatch: Open latch, and identify that the latch position status indicates that the latch is open; Close latch, and identify that the latch position status indicates that the latch is closed. Verification of latch position status shall be considered successful if the demonstration shows that all latch positions are accurately displayed on each side of each hatch. [HS5049V]

Rationale: No further Rationale required.

4.4.4.2.1.2 Hatch Closure

Hatch closure status shall be verified by demonstration. Demonstration shall occur in a qualification vehicle or a high-fidelity mockup. Demonstration shall consist of the following tasks: Opening hatch, and identifying that the hatch closure status indicates that the hatch is open; Closing hatch, and identifying that the hatch closure status indicates that the hatch is closed. The verification shall be considered successful when the demonstration shows that hatch closure status is displayed from each side of each hatch. [HS5016V]

Rationale: No further Rationale required.

4.4.4.2.1.3 Pressure Difference

Pressure difference measurement shall be verified by demonstration. Demonstration shall occur in the vehicle or high-fidelity mockup. The demonstration shall consist of one suited 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. [HS5050V]

Rationale: No further Rationale required.

4.4.4.2.1.4 Visual Observation

Direct visual observation of the opposite side of the hatch shall be verified by inspection. The inspection shall consist of a looking at the view through a window in high fidelity mockup. The verification shall be considered successful when inspection shows that the window provides direct visual observation of the opposite side of the hatch. [HS5017V]

Rationale: No further Rationale required.

4.4.5 WINDOWS

4.4.5.1 Optical Characteristics

Window optical characteristics shall be verified by inspection. The inspection shall confirm closure for the requirements in JSC 63307, "Optical Design and Verification Criteria for Windows in Human Space Flight Applications". The verification shall be considered successful when the inspection shows that the requirements within JSC 63307 have been closed. [HS5019V]

Rationale: No further Rationale required.

4.4.5.2 Piloting Tasks

Piloting windows shall be verified by analysis. The analysis shall use high fidelity computer graphic models. The models shall include the piloted vehicle, piloting crewmembers at pilot workstations, and all external objects required for piloting tasks such as the Earth, Moon, stars, and other vehicles. The analysis shall provide a graphical field of view out of the piloting windows. The verification shall be considered successful when the analysis shows that the field of view through the piloting windows provides a direct field of view for all NASA approved piloting tasks. [HS5021V]

Rationale: No further Rationale required.

4.4.5.3 External Observation

Observation window shall be verified by inspection. The inspection shall consist of a review of engineering drawings. The verification shall be considered successful when the inspection shows that a window has been provided for external observation. [HS5022V]

Rationale: No further Rationale required.

4.4.5.4 Covers and Shades without Tools

Window cover and shade removal without the use of tools shall be verified by demonstration. The demonstration shall occur in the vehicle or a high-fidelity mockup. The demonstration shall consist of removing or replacing each removable and replaceable window cover and shade. The verification shall be considered successful when the demonstration shows that each removal or replacement is completed without the use of tools. [HS5051V]

Rationale: No further Rationale required.

4.4.5.5 Covers and Shades in 60 seconds

Window cover and shade removal and replacement in 60 seconds shall be verified by demonstration. The demonstration shall occur in the vehicle or high-fidelity mockup. The demonstration shall consist of removing or replacing each removable and replaceable window cover and shade. The verification shall be considered successful when the demonstration shows that removal and replacement takes less than 60 seconds to complete. [HS5027V]

Rationale: No further Rationale required.

4.4.5.6 Obstruction

Window obstruction shall be verified by analysis. The analysis shall consist of a high-fidelity computer graphic model. The models shall include the vehicle in the flight configuration with all fixed equipment in place. The analysis shall determine the field of view out of each window. The verification shall be considered successful when the analysis show that the field of view out of any window is not obstructed by any fixed equipment. [HS5030V]

Rationale: No further Rationale required.

4.4.5.7 Internal Darkening

The provision and efficacy of window shades shall be verified by inspection and test. The inspection shall confirm that a shade has been provided for each window. The test shall fit all shades into place and measure the internal illumination near each window. The test configuration shall include an external light source equivalent to the illuminance of orbital sunlight at orbital noon and all internal light sources off, and with the majority of windows facing the external light source. The test measurement shall be at locations 0.5m +/-0.05m (~0.6 ft) along the inboard normal at the point of maximum observable illumination. The verification shall be considered successful when the inspection shows that a shade or an equivalent has been provided for each window and the test shows that the shades and any opaque external shutters and opaque internal protective covers, if so used, reduce the light level within the habitable volume to less than two (2) lux. [HS5031V]

Rationale: No further Rationale required.

4.4.5.8 Finishes

Not Applicable.

4.4.6 LIGHTING

4.4.6.1 Interior

4.4.6.1.1 General

Vehicle general lighting shall be verified by test. The test shall occur in a qualification vehicle or high-fidelity mockup. The test shall consist of measurements taken at 76 cm (30 in) (TBR-006-036) from each surface tangential to the light source. [HS5034V]

Rationale: No further Rationale required.

4.4.6.1.2 Task

Internal lighting levels shall be verified by test. The test locations for each task and lighing level listed in Table 3.4-1 shall be determined by a task analysis. The test shall occur in a qualification vehicle or high-fidelity mockup. The test shall consist of measuring the light levels at multiple locations for each task listed in Table 3.4-1, with the required general and task lighting on. The verification shall be considered successful when the test shows that all measured levels meet or exceed their corresponding levels in Table 3.4-1 [HS5035V]

Rationale: No further Rationale required.

4.4.6.1.3 General Light Adjustability

Vehicle general lighting shall be verified by test. The test shall be performed in a qualification vehicle or high-fidelity mockup. The test shall consist of measurements performed as specified in the individual vehicle requirements. These requirements explicitly state the location and orientation of the measurement as well as the minimum illumination level. The verification shall be considered successful when the test shows that the general lighting measurements meet or exceed the vehicle requirements. [HS5034BV]

Rationale: No further Rationale required.

4.4.6.2 Controls

4.4.6.2.1 Central

Vehicle general lighting controllability shall be verified by analysis. The analysis shall consist of identifying the number of vehicle general lights and lighting control (on/off and dimming) locations. The verification shall be considered successful when the analysis shows that all vehicle general lights can be controlled from a single location. [HS5039V]

Rationale: No further Rationale required.

4.4.6.2.2 Local

Task lighting control shall be verified by demonstration. The demonstration shall occur in a qualification vehicle or high-fidelity mockup. The demonstration shall consist of a subject restrained at a workstation, powering on and off the task lighting. The verification shall be considered successful when demonstration shows that the subject is able to control the task lighting from the restrained position. [HS5040V]

Rationale: No further Rationale required.

4.4.6.2.3 Restrained

Task lighting adjustability shall be verified by demonstration. The demonstration shall occur in a qualification vehicle or high-fidelity mockup. The demonstration shall consist of a subject restrained at a workstation, adjusting the position of the lighting, where applicable. The verification shall be considered successful when demonstration shows that the subject is able to adjust the task lighting from the restrained position. [HS5041V]

Rationale: No further Rationale required.

4.5 CREW FUNCTIONS

4.5.1 FOOD PREPARATION

4.5.1.1 Cross-Contamination

4.5.1.1.1 Cross-Contamination Prevention

Not Applicable [HS6001V]

4.5.1.1.2 Cross-Contamination Separation

Not Applicable

4.5.1.2 Preparation

4.5.1.2.1 Heating

The hot food and drink temperature shall be verified by test. The test shall use a flight-like unit. The test shall measure the temperature of the food and drink after heating. The verification shall be considered successful when the test shows that the system can heat food and drink to temperatures between 68°C (155 °F) and 79°C (175 °F). [HS6003V]

Rationale: No further Rationale required.

4.5.1.2.2 Rehydration

Rehydration of food and drinks shall be verified by demonstration. The demonstration shall consist of transferring potable water to the drink and food packages independent of gravity. The verification shall be considered successful when water can be transferred in quantities to rehydrate the items. [HS6004V]

Rationale: No further Rationale required.

4.5.1.2.3 In-Flight Food Preparation Time

Not Applicable

4.5.1.2.4 Lunar Surface Food Preparation Time

The preparation of food shall be verified by test and analysis. The test shall be performed in a high-fidelity mockup of the vehicle. The test shall record the time required for preparation of a meal for the maximum number of crewmembers for a vehicle configuration based on mission-specific food system requirements. The analysis shall take the time recorded from the test and multiply it by a program defined reduced gravity factor. The verification shall be considered successful when the test and analysis shows that 4 crew meals can be prepared within 30 minutes. [HS6102V]

Rationale: The verification will need to show that all food preparation tasks can be completed within an expected timeline. The analysis portion of this verification intends to account for the additional time typically required to complete tasks in a reduced gravity environment. The program will define the reduced gravity factor for each mission profile.

4.5.1.3 Food System

4.5.1.3.1 Food System

The nutritional content of the food system shall be verified by analysis. The analysis shall determine nutrient content of each food item. The analysis shall determine the nutrient content for a menu. The verification shall be considered successful when analysis shows the menu meets the nutritional requirements in Table 3.5-1 Nutritional Composition Breakdown (TBR-006-021). [HS6059V]

Rationale: No further Rationale required.

4.5.1.3.2 Metabolic Intake

The metabolic intake provisioning shall be verified by analysis. The analysis shall determine caloric content of each food item. In addition, further analysis shall determine the caloric content for a menu. The verification shall be considered successful when the analysis shows the menu meets 12,707 kJ (3035 kilocalories) per day. [HS6060V]

Rationale: No further Rationale required.

4.5.1.4 EVA Operations

4.5.1.4.1 Nutrition for Suited Operations

The additional nutrition for EVA suited operations shall be verified by analysis. The analysis shall determine the nutritional content of each food item available for consumption during EVA operations. The verification shall be considered successful when the analysis shows the food items meet the additional 837 kJ (200 kilocalories) per hour above nominal metabolic requirements for suited operations. [HS6062V]

Rationale: No further Rationale required.

4.5.1.4.2 Water for Suited Operations

The provisioning of water for EVA suited operations shall be verified by analysis. The analysis shall assess the potable water system as a whole. The verification shall be considered successful when the on-board total available potable water quantities provide 240 mL (8 ounces) of potable water per crewmember per EVA day for the maximum number of mission EVA days, in addition to other potable water requirements. [HS6063V]

Rationale: No further Rationale required.

4.5.2 PERSONAL HYGEINE

4.5.2.1 Privacy

Visual privacy during personal hygiene shall be verified by demonstration and analysis. The demonstration shall use a volumetrically accurate high fidelity mockup of the vehicle. The demonstration shall consist of subjects performing personal hygiene activities. The analysis shall extrapolate to 1st percentile female and 99th percentile male. The verification shall be considered successful when the demonstration and analysis show the largest male and smallest female crewmembers can complete all personal hygiene related activities with visual privacy. [HS6009V]

Rationale: No further Rationale required.

4.5.2.2 Stowage

Not Applicable

4.5.2.3 Trash

Not Applicable

4.5.2.4 Full Body Visual Privacy

Visual privacy during waste management shall be verified by Demonstration. The Demonstration shall consist of male and female subjects performing all body waste management activities using a high fidelity mock-up. The verification shall be considered successful when the demonstration shows a male and female crewmember can complete all body waste management related activities with full body visual privacy. [HS6027V]

Rationale: No further Rationale required.

4.5.2.5 Body Self-Inspection and Cleaning

Not Applicable

4.5.3 BODY WASTE MANAGEMENT

4.5.3.1 Vomitus

4.5.3.1.1 Collection and Containment

Vomitus collection and containment 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 an initial and repeated release into the collection system. The analysis shall determine the volume of the collection system. The verification shall be considered successful when the demonstration and analysis show that the collection system can collect and contain 0.5 liter per event for the number of events identified in Table 3.5-2 per crewmember for the duration of the mission. [HS6013V]

Rationale: No further Rationale required.

4.5.3.2 Feces

4.5.3.2.1 Wipes

The consumable wipe materials collection and containment shall be verified by analysis. The analysis shall determine the volume needed for accommodation of consumable wipe materials and shall identify controls for the escape of contents. The verification shall be considered successful when the analysis shows the volume needed for collection of consumable wipe materials is provided and escape of fecal contents is contained. [HS6016V]

Rationale: No further Rationale required.

4.5.3.2.2 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 the following: • A release into the collection system • A repeated release into the collection system. The analysis shall determine the volume of the collection system. The verification shall be considered successful when the analysis shows that 150g and 150mL of fecal matter per crewmember per defecation at an average of two defecations per day are contained. [HS6017V]

Rationale: No further Rationale required.

4.5.3.2.3 Feces, per Event

The collection and containment of fecal matter shall be verified by demonstration and inspection. The inspection shall determine of 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. 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, release is contained. [HS6020CV]

Rationale: No further Rationale required.

4.5.3.2.4 Diarrhea, per event

The collection and containment of diarrheal 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. The verification shall be considered successful when the analysis and demonstration show that the collection system can: • Hold 2L of diarrheal discharge in a single event • Release can be collected with no spillage or leakage • Release is contained. [HS6020V]

Rationale: No further Rationale required.

4.5.3.2.5 Diarrhea, per mission

The collection and containment of diarrheal discharge shall be verified by analysis and demonstration. 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 the following: • A release into the collection system • A repeated release into the collection system The verification shall be considered successful when the analysis and demonstration show that the collection system can: • Hold 8L of diarrheal events per crewmember for the duration of the mission • Release can be collected with no spillage • Release is contained • Repeated releases are contained with no leakage. [HS6018V]

Rationale: No further Rationale required.

4.5.3.2.6 Diarrhea, events per crewmember

The collection and containment of diarrheal events 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. The verification shall be considered successful when the analysis and demonstration show that the collection system can: • Hold 16 diarrheal events • Release can be collected with no spillage or leakage • Release is contained. [HS6020DV]

Rationale: No further Rationale required.

4.5.3.3 Urine

4.5.3.3.1 Containment

The collection and containment of urine shall be verified by demonstration. The demonstration shall be performed with flight-like hardware. The demonstration shall consist of a release into the collection system. The verification shall be considered successful when the demonstration shows that the collection system can: • Release of urine can be collected with no splash • Release is contained • Repeated releases are contained with no leakage. [HS6021V]

Rationale: No further Rationale required.

4.5.3.3.2 Wipes

The collection and containment of consumable wipes shall be verified by demonstration and inspection. The inspection shall determine of 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 disposing the consumable wipes into the collection system with a repeat disposal.

The verification shall be considered successful when the inspection and demonstration show that the collection system can:

• Hold consumable wipes for the duration of the mission • Wipes are collected • Wipes are contained • Repeated disposals are contained with no leakage. [HS6022V]

Rationale: The verification states that the Demonstration shall be completed in an analogous gravity environment. The verification must show that the method of collection and containment will work in the same gravity environments expected during the mission profiles.

4.5.3.3.3 Urine per Crewmember

The collection of urine shall be verified by inspection. The inspection shall determine the volume of the collection system. The verification shall be considered successful when the inspection shows that the collection system can hold the amount of urine specified by the equation per crewmember for the duration of the mission. [HS6023V]

Rationale: No further Rationale required.

4.5.3.3.4 Urine per Hour

The collection and containment of urine shall be verified by analysis and demonstration. The analysis shall determine the volume of the collection system and the ability of the system to accommodate urine. The demonstration shall be performed with flight-like hardware. The demonstration shall consist of six 1 L releases into the collection system in one hour. The verification shall be considered successful when the analysis and demonstration show that the collection system can: • Collect 6L of urine per hour • Release is contained • Repeated releases are contained with no leakage. [HS6024V]

Rationale: No further Rationale required.

4.5.3.3.5 Urine per Day

The collection and containment of urine shall be verified by analysis. The analysis shall determine the volumetric capacity of the collection system. The verification shall be considered successful when the analysis shows that the collection and containment system can contain 6 L of urine per crewmember for the duration of the mission. [HS6025BV]

Rationale: No further Rationale required.

4.5.3.3.6 Urine Rate

The collection of urine at a delivery rate shall be verified by demonstration. The demonstration shall be performed with flight-like hardware and shall show the collection system to accommodate the urine delivery rate independent of gravity. The demonstration shall consist of the following: • A release into the collection system • A repeated release into the collection system The verification shall be considered successful when the demonstration shows that the collection system can collect and contain urine at a maximum delivery rate of 0.4 L over 2 seconds. [HS6025V]

Rationale: No further Rationale required.

4.5.3.4 Defecation and Urination

4.5.3.4.1 Simultaneous

Simultaneous defecation and urination collection capability shall be verified by analysis and demonstration. The analysis shall include the bodily waste system interface that can accommodate male and female bodies. The demonstration shall be performed by male and female subjects with flight-like hardware. The demonstration shall consist of the subjects using the device for simulated simultaneous defecation and urination without full removal of lower clothing. The verification shall be considered successful when the analysis and demonstration show containment and no spillage during and after simultaneous collection without completely removing lower clothing. [HS6014V]

Rationale: No further Rationale required.

4.5.3.5 Odor Control

4.5.3.5.1 Waste Management Equipment

The odor control for waste management equipment shall be verified by demonstration and analysis. The demonstration shall consist of the placement of concentrated odor sources in a flight-like system in a high fidelity mock-up of the trash management system. The demonstration shall include the duration, environmental conditions and operations of an expected mission. A sniffer team shall determine whether the odor is contained during the demonstration. The analysis shall identify the design features implemented to control odors. The verification shall be considered successful when the demonstration and analysis show that the waste management system odors do not permeate the habitable volume of the vehicle. [HS6029V]

Rationale: The magnitude of odor is affected by time duration and temperature. In order to accurately determine whether odor control is attained, these variables should be considered.

4.5.3.5.2 Auditory and Olfactory Privacy

Not Applicable

4.5.3.6 Stowage

4.5.3.6.1 Waste Management Stowage

Waste management supply accessibility shall be verified by demonstration and analysis. The demonstration shall use a volumetrically accurate high fidelity mock-up. The demonstration shall show access to the supplies while restrained. The analysis shall extrapolate to the 1st percentile female and the 99th (TBR-006-030) percentile male. The verification shall be considered successful when the demonstration and analysis show that all associated equipment and supplies are accessible by the largest male and smallest female crewmembers while located at the waste management station. [HS6030V]

Rationale: No further Rationale required.

4.5.3.7 Trash

4.5.3.7.1 Waste Management Trash

Not Applicable

4.5.4 EXERCISE

4.5.4.1 Availability

4.5.4.1.1 Exercise Availability

The exercise capability shall be verified by analysis. The analysis shall determine the volume necessary to perform exercise, and the metabolic output of exercising crewmembers. The verification shall be considered successful when the analysis shows that adequate volume exists and atmospheric constituents remain within nominal levels during exercise. [HS6032V]

Rationale: No further Rationale required.

4.5.4.2 Operational Envelope

4.5.4.2.1 Exercise Operational Envelope

The exercise envelope shall be verified by inspection. The inspection shall determine that the operational envelope for deployed exercise equipment. The inspection shall occur in a volumetrically accurate high fidelity mockup in nominal non-dynamic mission configuration. The verification shall be considered successful when the inspection shows that the operational envelope available for exercise is 2.23m x 1.01m x 1.31m (7.3ft x 3.3ft x 4.3ft) (TBR-006-031). [HS6035V]

Rationale: The astronaut office will have a keen interest in the exercise envelope and while their approval is not specified in the verification requirement, it is expected that the astronaut office will have input during the design process.

4.5.4.3 Environmental Loads

4.5.4.3.1 Thermal Environment

The vehicle's response to environmental loads shall be verified by analysis. The analysis shall evaluate the vehicle systems' response to simultaneous metabolic loads as defined in Table E-2 Crew Induced Metabolic Loads in Appendix E. The verification shall be considered successful when the analysis shows that temperature inside the vehicle is maintained within the limits defined in HS3036 and HS3037. [HS6036V]

Rationale: No further Rationale required.

4.5.4.3.2 Oxygen

The vehicle's response to environmental loads shall be verified by analysis. The analysis shall evaluate the vehicle systems' response to simultaneous metabolic loads as defined in Table E-2 Crew Induced Metabolic Loads in Appendix E. The verification shall be considered successful when the analysis shows that oxygen partial pressure inside the vehicle is maintained within the limits defined in HS3005B. [HS6073V]

Rationale: No further Rationale required.

4.5.4.3.3 Carbon Dioxide

The vehicle's response to environmental loads shall be verified by analysis. The analysis shall evaluate the vehicle systems' response to simultaneous metabolic loads as defined in Table E-2 Crew Induced Metabolic Loads in Appendix E. The verification shall be considered successful when the analysis shows that CO2 inside the vehicle is maintained within the limits defined in HS3005. [HS6037V]

Rationale: No further Rationale required.

4.5.4.3.4 Relative Humidity

The vehicle's response to environmental loads shall be verified by analysis. The analysis shall evaluate the vehicle systems' response to simultaneous metabolic loads as defined in Table E-2 Crew Induced Metabolic Loads in Appendix E. The verification shall be considered successful when the analysis shows that water vapor inside the vehicle is maintained within the limits defined in HS3046. [HS6038V]

Rationale: No further Rationale required.

4.5.5 SPACE MEDICINE

4.5.5.1 Data and Communication

4.5.5.1.1 Private Voice

The vehicle's two-way private voice communication shall be verified by test. The test shall be an integrated test and shall consist of communications between the vehicle and designated mission control center flight control team positions using flight-like avionics. The verification shall be considered successful when the test shows that audio transmitted between the vehicle and the mission control center can only be heard on orbit and at the designated flight control team positions. [HS6075V]

Rationale: No further Rationale required.

4.5.5.1.2 Private Video

The vehicle's private video communication shall be verified by test. The test shall be an integrated test and shall consist of a simulated video communication between the vehicle and designated mission control center flight control team positions using flight-like avionics. The verification shall be considered successful when the test shows that video transmitted between the vehicle and the mission control center can only be seen on orbit and at the designated flight control team positions. [HS6076V]

Rationale: No further Rationale required.

4.5.5.1.3 Communication Capabilities

The social correspondence link requirement shall be verified by demonstration. The demonstration shall consist of using the flight communication systems to exchange information with earth-bound individuals over a private link. The verification shall be considered successful when the demonstration shows that crewmembers can exchange audio, text, and video information with earth-bound individuals using flight communication systems with a delivery delay of less than 4 hours (TBR-006-051). [HS6097V]

Rationale: No further Rationale required.

4.5.5.1.4 Personalized In-Flight Updates

The recreational database updating capability requirement shall be verified by demonstration. The demonstration shall consist of using the flight communication systems to update the personalized recreational on-board database with new personal information, recreational software, music, videos, books, and magazines from the mission control center. The verification shall be considered successful when the personalized recreational on-board database is shown to be accurately updated. [HS6099V]

Rationale: No further Rationale required.

4.5.5.1.5 Biomedical Data

The collection of biomedical telemetry from the suit shall be verified by test. The test shall be an integrated test and consist of sending a simulated biomedical telemetry from the suit to the vehicle using flight-like hardware. The verification shall be considered successful when the demonstration shows that biomedical telemetry is transmitted from the pressure suit to the vehicle. [HS6077V]

Rationale: No further Rationale required.

4.5.5.1.6 Biomedical Relay

The relay of suited biomedical telemetry shall be verified by test. The test shall be an integrated test and shall consist of transmitting suited biomedical telemetry to the mission control center from the vehicle under conditions simulating spaceflight using flight-like avionics. The verification shall be considered successful when the test shows that biomedical telemetry is transmitted from the pressure suit to the mission control center. [HS6078V]

Rationale: No further Rationale required.

4.5.5.1.7 Biomedical Display

The display of biomedical telemetry to on crewmembers shall be verified by demonstration. The demonstration shall send simulated biomedical telemetry to the crew displays to using flight like hardware. The verification shall be considered successful when the demonstration shows that biomedical telemetry is displayed to crewmembers. [HS6079V]

Rationale: No further Rationale required.

4.5.5.2 Vehicle Pressure

4.5.5.2.1 DCS Repressurization

The vehicle pressurization from vacuum to nominal operating pressure shall be verified by analysis. The analysis shall determine the time required to increase the internal pressure from vacuum to nominal operating pressure. The verification shall be considered successful when the analysis shows that the time required to achieve nominal operating pressure is 15 minutes. [HS6080V]

Rationale: No further Rationale required.

4.5.5.2.2 DCS Overpressurization

Decompression sickness (DCS) treatment capabilities shall be verified by analysis. The analysis shall evaluate the vehicle's ability to deliver nominal vehicle pressure plus 27.6 kPa (4 psi) (207 mmHg) plus nominal pressure suit operating pressure to crewmember(s), assuming the vehicle begins at a state of vacuum and assuming the crewmember is not suited at the time the need for treatment is realized. The verification shall be considered successful when the analysis shows that the specified pressure can be achieved to crewmember(s) within 20 minutes, and maintained for 6 hours (TBR-006-016). [HS6081V]

Rationale: No further Rationale required.

4.5.5.2.3 DCS Event Pressure

The Constellation Architecture's decompression sickness (DCS) initial treatment capability shall be verified by test. The test shall use a structurally flight-like mockup to simulate a recovery from an EVA DCS scenario, initiating DCS treatment, and measuring the atmospheric pressure at the skin surface of a dummy crew member, assuming that the recovery/treatment chamber pressure is initially less than 55.2 kPa (8 psi) (413 mmHg) and that the dummy crewmember is suited at the time the treatment begins. The verification shall be considered successful when the test shows that 55.2 kPa (8 psi) (413 mmHg) or more of atmospheric pressure is measured at the dummy crewmember's skin within 20 minutes of test onset. [HS6100V]

Rationale: No further Rationale required.

4.5.5.2.4 Denitrogenation

The maintaining of internal pressure and gaseous composition for denitrogenation shall be verified by analysis. The demonstration shall adjust to various gaseous pressures and concentrations defined in Table (TBD-006-008) in an integrated configuration of vehicle including the suit. The verification shall be considered successful when the demonstration shows the vehicle can vary pressures and gas concentrations per the denitrogenation protocol. [HS6091V]

Rationale: No further Rationale required.

4.5.5.3 Orthostatic Protection

4.5.5.3.1 Orthostatic Protection

The provisioning of crewmember orthostatic protection shall be verified by analysis. The analysis shall identify the vehicle's countermeasure capabilities to combat end of mission orthostasis. The verification shall be considered successful when it is shown the vehicle protects the crewmember from orthostatic fluid shifts during re-entry and landing while allowing the crewmember to complete tasks associated with those mission phases. [HS6082V]

Rationale: No further Rationale required.

4.5.5.4 Interfaces

4.5.5.4.1 Interfaces

The medical equipment interfaces shall be verified by inspection. The inspection shall confirm the closure of the medical equipment interfaces specified in the Portable Equipment Payloads and Cargo IRD (CxP 70035). The verification shall be considered successful when the inspection shows that the medical equipment interface requirements within the Portable Equipment Payloads and Cargo IRD (CxP 70035) are closed. [HS6095V]

Rationale: No further Rationale required.

4.5.5.5 Medical Area and Capability

4.5.5.5.1 Medical Care Provider Access

The medical provider access to ill/injured crewmember shall be verified by demonstration and analysis. The demonstration shall consist of a subject providing medical treatment to another subject in the medical area within a volumetrically accurate mockup. The analysis shall extrapolate the demonstration to include all applicable mission phases. The verification shall be considered successful when the demonstration and analysis show a medical provider can access the ill/injured crewmember in the medical area to provide various levels of care during all applicable mission phases. [HS6083V]

Rationale: No further Rationale required.

4.5.5.5.2 Patient Electrical Isolation

The patient electrical isolation shall be verified by analysis. The analysis shall determine how a crewmember will be restrained in the medical seat for defibrillation. The analysis shall evaluate how electrical isolation from the vehicle is achieved. The verification shall be considered successful when the analysis shows a crewmember is electrically isolated from the rest of the vehicle. [HS6084V]

Rationale: No further Rationale required.

4.5.5.5.3 Access to Medical Equipment

The interfaces from medical equipment to patient shall be verified by demonstration. The demonstration shall configure pieces of medical hardware secured and being used with a surrogate ill/injured crewmember in the medical area in a volumetrically accurate mockup. The verification shall be considered successful when the hardware interfaces with the surrogate as required to perform function safely. [HS6085V]

Rationale: No further Rationale required.

4.5.5.5.4 Access to Deployed Medical Kits

The medical kit proximity to provider shall be verified by analysis. The analysis shall consist of a worksite analysis to determine where the medical kits shall be deployed. The verification shall be considered successful when the analysis shows that the medical provider can reach the crewmember in the medical seat and the medical kit in a volumetrically accurate mockup. [HS6086V]

Rationale: A worksite analysis will determine if all medical provider tasks can be completed when considering the identified location of the deployed medical kits.

4.5.5.5.5 Medical Care Capabilities

The medical care capabilities shall be verified by inspection. The inspection shall confirm closure of the requirements in Portable Equipment, Payloads and Cargo IRD, CxP 70035 and the Portable Equipment SRD, for the mission's level of care capabilities in Table 3.5-3, Medical Care Capabilities. The verification shall be considered successful when the inspection shows that the requirements in the Portable Equipment, Payloads and Cargo IRD, CxP 70035 and the Portable Equipment SRD, are closed. [HS6101V]

Rationale: No further Rationale required.

4.5.5.6 Crew Sleep Accommodations

4.5.5.6.1 Crew Sleep Accommodations

Accommodations for crew sleep shall be verified by inspection. The inspection shall consist of a review of engineering drawings and the available restraints to maintain a sleeping position. The verification shall be considered successful when the inspection shows that accommodations for crew sleep have been provided. [HS6104V]

Rationale: No further rationale required.

4.5.6 STOWAGE

4.5.6.1 Stowage Nominal Operation

Not Applicable

4.5.6.2 Stowage Location

Not applicable.

4.5.6.3 Stowage Arrangement

Not Applicable

4.5.6.4 Stowage Reconfiguration

Not Applicable

4.5.6.5 Stowage Restraints

The restraint of stowed items during periods of expected acceleration and vibration shall be verified by analysis. The analysis shall evaluate the affect of expected acceleration and vibration on the restraints of stowed items. The verification shall be considered successful when the analysis shows the restraint system is sufficient for the volume and mass of stowed items. [HS6050V]

Rationale: No further Rationale required.

4.5.6.6 Stowage Hand Operation

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 consists of a subject accessing and operating stowage compartments. The verification shall be considered successful when the demonstration shows that all stowage compartments are accessible and operable without the use of any tools. [HS6051V]

Rationale: No further Rationale required.

4.5.6.7 Stowage Commonality

Not Applicable

4.5.6.8 Stowage Compatibility with Inventory Management

The stowage system's compatibility with the inventory management system shall be verified by analysis. The analysis shall determine if the inventory management system can be used with all stowage without modification. The verification shall be considered successful when the analysis shows that the stowage system can be inventoried by the inventory management system. [HS6053V]

Rationale: No further Rationale required.

4.5.7 TRASH MANAGEMENT

4.5.7.1 Trash Management Nominal Operation

Not Applicable

4.5.7.2 Trash Management Odor Control

The odor control for waste management equipment shall be verified by demonstration and analysis. The demonstration shall consist of the placement of concentrated odor sources in a flight-like system in a high fidelity mock-up of the trash management system. The demonstration shall include the duration, environmental conditions and operations of an expected mission. A sniffer team shall determine whether the odor is contained during the demonstration. The analysis shall identify the design features implemented to control odors. The verification shall be considered successful when the demonstration and analysis show that the waste management system odors do not permeate the habitable volume of the vehicle. [HS6056V]

Rationale: No further Rationale required.

4.5.7.3 Trash Management Contamination Control

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. The verification shall be considered successful when the analysis shows that microorganisms are trash is not released outside of the trash management system. [HS6057V]

Rationale: No further Rationale required.

4.5.7.4 Trash Management Hazard Containment

The trash management containment of its contents shall be verified by demonstration. The demonstration shall consist of disposing items, including biological waste, into the trash management system and showing that containment is independant of gravity. The verification shall be considered successful when the demonstration shows that the trash management system contains these waste items. [HS6058V]

Rationale: No further Rationale required.

4.6 CREW INTERFACES FOR DISPLAYS AND CONTROLS

4.6.1 GENERAL

4.6.1.1 Consistent Crew Interfaces

Not Applicable

4.6.1.2 Labeling

Labeling shall be verified by inspection. The inspection shall examine crew interface controls and data items for labels. The verification shall be considered successful when the inspection indicates that all controls and data items have an associated label. [HS7036V]

Rationale: No further Rationale required.

4.6.1.3 Labeling Standardization

Labels, decals and placards shall be verified by inspection. The inspection shall examine all labels, decals and placards. The verification shall be considered successful when the inspection indicates that all labels, decals and placards comply with the requirements in Appendix L (TBR-006-053). [HS7078V]

Rationale: No further Rationale required.

4.6.1.4 Nomenclature

Nomenclature compliance to CxP 70019 - Constellation Nomenclature Plan shall be verified by inspection. The verification shall be considered successful when the inspection indicates that all nomenclature items related to on-orbit operations have been approved by a panel chartered under the CxSECB as outlined in CxP 70019. [HS7079V]

4.6.1.5 Legibility

The legibility of crew interfaces shall be verified by analysis and test. The analysis shall simulate reading under the full range of nominal lighting, acceleration, and vibration environmental conditions. Tests shall collect human reading data under a limited set of worst-case conditions to validate and certify the spaceflight legibility model used to assess legibility under all nominal spaceflight conditions. The verification shall be considered successful when the analysis shows that crew interfaces are legible under all nominal conditions. [HS7044V]

Rationale: No further Rationale required.

4.6.1.6 Language

The American English language requirement shall be verified by inspection. The inspection shall be performed on display text, hardcopy procedures and cue cards, labels, and placards. The verification shall be considered successful when the inspection shows that all text is found to be written in the English language according to Webster's New World Dictionary of American English and CxP 70072ANX02, the Constellation Program Management Systems Plan, Annex 02: Common Glossary, Acronyms and Nomenclature list. [HS7064V]

Rationale: This requirement may be a candidate for a higher-level document. It is residing in the HSIR until another appropriate document is identified. The verification may change or not be necessary.

4.6.1.7 Units of Measure

Units of measure shall be verified by inspection. The inspection shall be performed on display text, the data which feeds the display (to confirm same units as in the text, labels, and placards. The verification shall be considered successful when the inspection shows that all values are found to be in the International System of Units (SI) units of measure. [HS7065V]

Rationale: Verification by inspection is appropriate, since by verifying the display and the data files that support the displays, the units of measure can be seen.

4.6.1.8 Use of Color

The redundancy of color interface cues shall be verified by demonstration. The demonstration shall first identify all interface components that use color to convey meaning. The demonstration shall then determine whether the identified color-coded interface components also provide a second cue to convey that meaning. The verification shall be considered successful when the demonstration shows that all color-coded interface components provide a second non-color cue when color is used to convey meaning. [HS7065AV]

Rationale: Demonstration is used to account for situations that involve processes or caution and warning, which would require interaction with the system rather than inspection of the system/drawings.

4.6.2 CREW PERFORMANCE

4.6.2.1 Crew Interface Usability

4.6.2.1.1 Crew Interface Usability-Nominal

Crew interface usability shall be verified by analysis (TBR-006-056). An analysis shall consist of usability evaluations using 20 participants who are crew or representative of the crew population. Per usability evaluation guidelines, as described in "Usability Engineering" (1993) by Jakob Nielsen, participants will be asked to perform a set of high-fidelity onboard tasks in a flight-like simulator or mockup using the crew interface. The usability error rate will be computed as a percentage, (i.e., ratio of number of errors to number of task steps performed). The verification shall be considered successful when the analysis shows that usability error rate is less than or equal to 5% (TBR-006-072). [HS7066V]

Rationale: "Usability Engineering" (1993) by Jakob Nielsen suggests 20-25 users if one wants to get a larger than 80% confidence interval on the measures.

4.6.2.1.2 Crew Interface Usability - Loss of Crew/Vehicle/Mission

Crew interface usability shall be verified by analysis (TBR-006-059). An analysis shall consist of usability evaluations using 20 participants who are crew or representative of the crew population. Per usability evaluation guidelines, as described in "Usability Engineering" (1993) by Jakob Nielsen, participants will be asked to perform a set of high-fidelity onboard tasks in a flight-like simulator or mockup using the crew interface. The usability error rate will be computed as a percentage, (i.e., ratio of number of errors to number of task steps performed). The verification shall be considered successful when the analysis shows that usability error rate is less than or equal to 1% (TBR-006-071). [HS7081V]

Rationale: "Usability Engineering" (1993) by Jakob Nielsen suggests 20-25 users if one wants to get a larger than 80% confidence interval on the measures.

4.6.2.2 Crew Cognitive Workload

4.6.2.2.1 Workload Measures – Nominal

The mission-safety workload shall be verified by analysis (TBR-006-064). A list of crew tasks that can result in loss of mission will be provided as part of a task analysis. The analysis shall consist of an evaluation of at least 8 trained personnel performing each of the listed crew tasks in a flight-like simulator or mockup and providing workload ratings on the TLX scale. The verification shall be considered successful when the test shows that, for modeled nominal tasks , there is 95% confidence that the median of the TLX rating does not exceed 40 (TBR-006-058). [HS7080V]

Rationale: Workload is to be assessed repeatedly by highly trained individuals immediately following dynamic human-in-the-loop simulations of tasks that can distract or overwork the crew in a full-mission (multi-crew) facility. It is intended that this requirement be met for a reasonable sample of nominal and non-critical failure tasks and combinations of tasks that may reasonably be performed simultaneously by the crew.

4.6.2.2.2 Workload Measures – "Loss of Crew/Vehicle"

The crew-safety workload shall be verified by analysis (TBR-006-054). A list of crew tasks that can result in loss of crew or loss of vehicle will be provided as part of a task analysis. The test shall consist of at least 8 trained personnel performing each of the listed crew tasks in a flight-like simulator or mockup and providing workload ratings on the TLX scale. The verification shall be considered successful when the test shows that for all tasks that could result in crew or vehicle loss, there is 95% confidence that the median of the TLX rating does not exceed 30 (TBR-006-065). [HS7001V]

Rationale: Workload is to be assessed repeatedly by highly trained individuals immediately following dynamic human-in-the-loop simulations of tasks that can result in loss of crew or loss of vehicle in a full-mission (multi-crew) facility. It is intended that this requirement be met for a reasonable sample of systems failures and combinations of tasks that may reasonably be performed simultaneously by the crew.

4.6.2.2.3 Workload Measures – "Loss of Mission"

The mission-safety workload shall be verified by analysis (TBR-006-055). A list of crew tasks that can result in loss of mission will be provided as part of a task analysis. The test shall consist of at least 8 trained personnel performing each of the listed crew tasks in a flight-like simulator or mockup and providing workload ratings on the TLX scale. The verification shall be considered successful when the test shows that, for all tasks that could result in mission loss, there is 95% confidence that the median of the TLX rating does not exceed 40 (TBR-006-066). [HS7002V]

Rationale: Workload is to be assessed repeatedly by highly trained individuals immediately following dynamic human-in-the-loop simulations of tasks that can result in loss of mission in a full-mission (multi-crew) facility. It is intended that this requirement be met for a reasonable sample of systems failures and combinations of tasks that may reasonably be performed simultaneously by the crew.

4.6.2.3 Handling Qualities

4.6.2.3.1 Handling Quality ratings – "Loss of Crew/Vehicle"

The crew-safety handling quality rating shall be verified by test. A list of vehicle control tasks that can result in loss of crew or loss of mission will be provided as part of a task analysis. The test shall consist of at least 5 astronaut pilots performing the listed control tasks in a flight-like simulator or mockup and providing handling-quality ratings on the Cooper-Harper scale. The verification shall be considered successful when the test shows that, for all tasks that could result in crew or vehicle loss, no individual Cooper-Harper rating exceeds 2. [HS7003V]

Rationale: Handling quality is to be assessed repeatedly by highly trained individuals immediately following dynamic human-in-the-loop simulations of single-failure malfunctions and nominal operations in a full-mission (multi-crew) facility. It is intended that this requirement be met for a reasonable sample of systems failures and combinations of tasks that may reasonably be performed simultaneously by the crew. Individual ratings are used here because the population is homogeneous and is trained on the rating scale. It also provides a more stringent rating because the tasks include critical flight operations.

4.6.2.3.2 Handling Quality ratings – "Loss of Mission"

The mission-safety handling quality rating shall be verified by test. A list of vehicle control tasks that can result in loss of crew or loss of mission will be provided as part of a task analysis. The test shall consist of at least 5 Astronaut pilots performing the listed control tasks and providing handling-quality ratings on the Cooper-Harper scale. The verification shall be considered successful when the test shows that, for all tasks that could result in mission loss, no individual Cooper-Harper rating exceeds 3. [HS7004V]

Rationale: Handling quality is to be assessed repeatedly by highly trained individuals immediately following dynamic human-in-the-loop simulations of single-failure malfunctions and nominal operations in a full-mission (multi-crew) facility. It is intended that this requirement be met for a reasonable sample of systems failures and combinations of tasks that may reasonably be performed simultaneously by the crew. Individual ratings are used here because the population is homogeneous and is trained on the rating scale. It also provides a more stringent rating because the tasks include critical flight operations.

4.6.3 DISPLAY AND CONTROL LAYOUT

4.6.3.1 Viewing Requirements

4.6.3.1.1 Field of View

The visibility of viewed displays and controls shall be verified by analysis. The analysis shall consist of a geometric worst-case calculation of the field of regard of a suited and seated crew member. The verification shall be considered successful when the analysis shows that all displays and controls, which need to be viewed for operation, are fully within the field of view of a suited and seated crew member. [HS7010V]

Rationale: No further Rationale required.

4.6.3.1.2 Two-crew Operations

The capability of two operators to view and confirm each other's inputs for mission critical functions shall be verified by demonstration. The demonstration shall use a list of mission critical functions determined by a task analysis. The demonstration shall include 2 trained personnel performing mission critical functions in a flight-like simulator or mockup with the flight configuration of seating, controls and displays. The verification shall be considered successful when the demonstration shows that the vehicle provides display location for personnel to view each other's operations for all mission critical functions. [HS7010AV]

Rationale: No further Rationale required.

4.6.3.1.3 Viewing Critical Displays and Controls

Not Applicable

4.6.3.1.4 Viewing Frequently Used Displays and Controls

Not Applicable

4.6.3.1.5 Obscured Controls

Distinguishabilty 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. 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 fewer than 1% erroneous control selections. [HS7067V]

Rationale: No further Rationale required.

4.6.3.2 Reach Requirements

4.6.3.2.1 Functional Reach Envelope

The location of controls within the crew members' functional reach shall be verified by analysis. The analysis shall consist of a geometric worst-case calculation of the reach envelope of a suited and seated crew member. The verification shall be considered successful when the analysis shows that all controls for each task are located within the reach envelope of the seated and suited crew member performing the task. [HS7019V]

Rationale: No further Rationale required.

4.6.3.2.2 Reach for Critical Controls

Not Applicable

4.6.3.2.3 Reach for Frequently Used Controls

Not Applicable

4.6.3.3 Display and Control Grouping

4.6.3.3.1 Functional Related Displays and Controls

Not Applicable

4.6.3.3.2 Successive Operation of Displays and Controls

Not Applicable

4.6.3.4 Control Spacing

4.6.3.4.1 Control Spacing for Suited Operations

Spacing of hand operated controls for gloved operations shall be verified by demonstration. The demonstration shall be performed using a list of controls used by gloved crewmembers as determined by a task analysis. The demonstration will use trained personnel, wearing a flight-like glove, representing the full anthropometric range of crewmembers. The demonstration will be conducted in a flight-like simulator or mockup. The verification shall be considered successful when the demonstration shows that hand operated controls used for gloved operations are spaced such that the controls can be operated without interfering with nearby controls. [HS7024V]

Rationale: No further Rationale required.

4.6.3.4.2 Control Spacing for Unsuited Operation

Spacing of hand operated controls for ungloved operations shall be verified by demonstration. The demonstration shall be performed using a list of controls used by ungloved crewmembers as determined by a task analysis. The demonstration will use trained personnel representing the full anthropometric range of crewmembers. The demonstration will be conducted in a flight-like simulator or mockup. The verification shall be considered successful when the demonstration shows that hand operated controls used for ungloved operations are spaced such that the controls can be operated. [HS7925V]

Rationale: No further Rationale required.

4.6.4 DISPLAYS

4.6.4.1 Display Content

4.6.4.1.1 Task Oriented Displays

The availability of task-orientated displays shall be verified by inspection. The inspection shall determine the availability of a task-oriented display for each task. The verification shall be considered successful when the inspection confirms the existence of a task-oriented display associated with each task. [HS7059V]

Rationale: No further Rationale required.

4.6.4.1.2 Subsystem Orientated Displays

The availability of subsystem-orientated displays shall be verified by inspection. The inspection shall determine the availability of a subsystem-oriented display for each subsystem. The verification shall be considered successful when the inspection confirms the existence of a subsystem-oriented display associated with each subsystem. [HS7060V]

Rationale: No further Rationale required.

4.6.4.1.3 Viewing Simultaneous Task Information

Not Applicable

4.6.4.1.4 Viewing Simultaneous Critical Task Information

Simultaneous viewing of critical task information shall be verified by analysis. The analysis shall determine for each critical task whether or not all of the task information needed to perform the task can be simultaneously displayed within the field of regard of a suited and seated crew member performing the task. The verification shall be considered successful when the analysis shows that the vehicle can simultaneously display all information needed for each critical task within the field of regard of a single seated and suited crew member. [HS7070V]

Rationale: No further Rationale required.

4.6.4.2 Display Hierarchy

4.6.4.2.1 Location within the Display Hierarchy

Location within the visual display hierarchy shall be verified by demonstration. The demonstration shall consist of navigation through each of the displays using flight software and flight-like display device hardware. The verification shall be considered successful when the demonstration shows that each display offers an opportunity to view one’s location within the display hierarchy. [HS7061V]

Rationale: No further Rationale required.

4.6.4.2.2 Access Within Display Hierarchy

Not Applicable

4.6.4.3 System Feedback

4.6.4.3.1 State Change

Data update rate for state change shall be verified by test. The test shall be performed with flight-configuration software and hardware. The test shall run a scenario that simulates a display parameter changing on multiple displays. The verification shall be considered successful when the test shows that the updated data parameter is shown on all associated displays within 1.0 second (TBR-006-029) of the change on the display where the input was originated. [HS7072V]

Rationale: No further Rationale required.

4.6.4.3.2 Lost Data

Loss of displayed data parameters shall be verified by demonstration. The demonstration shall be performed using flight-configuration software, and a list of representative data types from a task analysis. The software shall run a scenario that results in the loss of data parameters for the data sets being tested. The verification shall be considered successful when the demonstration shows that the vehicle provides an indication that the parameters for each tested data set is unavailable. [HS7072AV]

Rationale: No further Rationale required.

4.6.5 HARDWARE AND SOFTWARE CONTROLS

4.6.5.1 Control Operations

4.6.5.1.1 Compatibility of Movement

Input-output compatibility shall be verified by demonstration. The demonstration shall use flight-configuration hardware and software controls. The demonstration shall consist of activation of the controls and noting the control response. The verification shall be considered successful when the demonstration shows that the input-output mapping is compatible as defined in the (TBD-006-051) compatibility table K-1 in Appendix K. [HS7063V]

Rationale: No further Rationale required.

4.6.5.1.2 Control Feedback

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. [HS7063AV]

Rationale: No further Rationale required.

4.6.5.1.3 Protection Against Inadvertent Activation

Not Applicable.

4.6.5.1.4 Protection for Critical Controls

Protection for critical controls shall be verified by demonstration. The demonstration shall consist of the activation of a list of critical flight-configuration hardware and software controls as determined by a task analysis. The verification shall be considered successful when the demonstration shows that the controls have two independent crew actions for activation. [HS7063CV]

Rationale: No further Rationale required.

4.6.5.1.5 Coding for Emergency and Critical Controls

Coding for emergency and critical controls shall be verified by inspection. The inspection shall involve all controls on the list of emergency and critical controls as defined in a NASA-approved task analysis. The inspection shall determine whether coding is compliant with the (TBD-006-013) emergency coding table. The verification shall be considered successful when the inspection shows that coding meets the TBD emergency coding table K-2 in Appendix K. [HS7063DV]

Rationale: No further Rationale required.

4.6.5.1.6 Restraints for Control Operation

Restraints for reduced gravity control operations shall be verified by analysis. The analysis will use a list of controls required during reduced gravity crew operations as determined by a task analysis. The analysis shall consist of computer models of the forces during control operations to determine if the restraints will allow proper operation of controls, taking into account the full anthropometric range and force capabilities of crewmembers. The verification shall be considered successful when the analysis shows that the restraint system(s) provided will allow proper application of the forces necessary for the full-range of operation of controls used during reduced gravity. [HS7063EV]

Rationale: No further Rationale required.

4.6.5.2 High-g Operation

4.6.5.2.1 Over 3 g

Control placement for operations at 3 g or more shall be verified by analysis. The analysis shall be performed using a list of controls used during operations at 3 g or more as determined by a task analysis. The analysis shall determine whether the controls can be accessed by a hand/wrist movements of a restrained/supported arm taking into account the full anthropometric range of crewmembers. The verification shall be considered successful when the analysis shows that controls used in operations at 3 g or more are accessible by hand/wrist movements of a restrained/supported arm. [HS7027V]

Rationale: No further Rationale required.

4.6.5.2.2 Over 2 g

Control placement for operations between 2 g and 3 g shall be verified by analysis. The analysis shall be performed using a list of controls used during operations between 2 g and 3 g as determined by a task analysis. The analysis shall determine whether the controls can be accessed either by hand/wrist movements of a restrained/supported arm or by forward reaches taking into account the full anthropometric range of crewmembers. The verification shall be considered successful when the analysis shows that controls used during operations between 2 g and 3 g are accessible by hand/wrist movements of a restrained/supported arm or by a reach within a forward +/- 30 degree (TBR-006-027) cone. [HS7028V]

Rationale: No further Rationale required.

4.6.5.2.3 Supports

Limb support for control operations during accelerations between 2 g and 6 g (TBR-006-024) conditions shall be determined by analysis. The analysis shall be performed by using a CAD model to determine the wrist/hand placement/access to critical controls while limbs are restrained. The verification shall be considered successful when the analysis shows that limb support and control placement fall within the limits of hand/wrist reach. [HS7029V]

Rationale: No further Rationale required.

4.6.6 CREW NOTIFICATION AND CAUTION AND WARNING

4.6.6.1 Crew Notifications

4.6.6.1.1 Notifications

Crew notification of required mission critical actions shall be verified by demonstration. The demonstration shall use a list of mission critical action scenarios as determined from a task analysis. The demonstration shall be performed with flight hardware and software running the mission critical action scenarios. The verification shall be considered successful when the demonstration shows that notifications are received when mission critical actions are required. [HS7049V]

Rationale: No further Rationale required.

4.6.6.1.2 Manual Silencing

The manual silencing feature for auditory annunciators shall be verified by demonstration. The demonstration shall be performed on flight-configuration hardware and software. The annunciators will be activated and the manual silencing feature will be selected. The verification shall be considered successful when the demonstration shows that activating the manual silencing feature silences the active auditory annunciators. [HS7049AV]

Rationale: No further Rationale required.

4.6.6.1.3 Volume Control for Auditory Annunciations

Auditory annunciation volume control shall be verified by test. The test shall be made with flight hardware and software. Auditory annunciations will be activated and the volume adjusted. Aural-anunciation volume control shall be verified by test. The test shall be made with flight hardware and software. Aural nnunciations will be activated and the volume adjusted. Measurements shall be made, using a Type 1 integrating-averaging sound level meter, at expected head locations at the receiving station. The verification shall be considered successful when the test shows that the measured volume of aural nnunciations, other than cautions and warnings, vary from 5 to 100% of maximum across the full range of the volume control. [HS7075V]

Rationale: No further Rationale required.

4.6.6.1.4 Speech Intelligibility

Auditory speech annunciations and communications intelligibility shall be verified by test and analysis. The test shall be made with flight-configuration hardware and software. The methodology given in ANSI S.3.2-1989 (TBR-006-057) shall be used. The background noise spectrum shall be derived from actual background noise measurements in the habitable volume, e.g., those obtained from HS3076. The verification shall be considered successful when analysis indicates a calculated articulation index of 0.7 or higher at the ear of the listener, throughout the habitable volume. [HS7076V]

Rationale: 1) Prototype or qualification annunciation and communication system designs should be tested by analysis prior to manufacture of the actual annunciation and communication system.

2) 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.

4.6.6.1.5 Volume Control for Audio Communications

Voice-channel volume control shall be verified by test. The test shall be made with flight hardware and software. Audio channels carrying voice will be activated and the volume adjusted while an operator speaks into the microphone at the sending station. Measurements shall be made, using a Type 1 integrating-averaging sound level meter, at expected head locations at the receiving station. The verification shall be considered successful when the test shows that the measured volume of each audio channel carrying voice communications varies 5 to 100% of maximum across the full range of the volume control. [HS7077V]

Rationale: No further Rationale required.

4.6.6.2 Caution and Warning

4.6.6.2.1 Annunciation Hierarchy

Off-nominal event classification shall be verified by demonstration. The demonstration shall be performed using flight-configuration software. The demonstration shall consist of the simulation of all contemplated off-nominal events and the classification of these events. The verification shall be considered successful when the demonstration shows that each off-nominal event is correctly assigned to one of the classifications. [HS9029V]

Rationale: No further Rationale required.

4.6.6.2.2 Annunciation Prioritization

Prioritization of caution and warning annunciations shall be performed by demonstration. The demonstration shall be performed on flight-configuration Caution and Warning System using all contemplated pairs of simultaneous off-nominal events. The verification shall be considered successful when the demonstration shows the vehicle's caution and warning system correctly prioritizes the caution and warnings. [HS9029AV]

Rationale: No further Rationale required.

4.6.6.2.3 Visual and Auditory Annunciation

Visual and auditory annunciations of emergency, warning, and caution events shall be verified by demonstration. The demonstration shall be performed using flight-configuration software and hardware and all contemplated emergency, warning, and caution events. The verification shall be considered successful when the demonstration shows that each emergency, warning, and caution event triggers the correct visual and auditory annunciations. [HS9030V]

Rationale: No further Rationale required.

4.6.6.2.4 Distinctiveness of Annunciations

Consistency of non-speech aural annunciations shall be verified by demonstration. The demonstration shall be performed on all non-speech aural annunciations using a flight-configuration audio system to annunciate the signals. Signal content will be compared to the (TBD-006-014) Caution and Warning Annunciation Table K-3 in Appendix K. The verification shall be considered successful when the demonstration shows that all non-speech aural annunciations meet the (TBD-006-014) Caution and Warning Annunciation Table K-3 in Appendix K. [HS9032V]

Rationale: No further Rationale required.

4.6.6.2.5 Loss of Annunciation Capability

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. The verification shall be considered successful when test shows that the vehicle provides notification of either auditory or visual annunciator system failure. [HS9032AV]

Rationale: No further Rationale required.

4.6.7 CREW SYSTEM INTERACTION

4.6.7.1 Subsystem State Information

Subsystem state information shall be verified by demonstration. The demonstration shall be performed using flight-configuration software and a list of representative subsystems from a task analysis. The demonstration shall involve requesting the display of subsystem states from the test data set. The verification shall be considered successful when the demonstration shows that all requested subsystem state information is displayed to the crew. [HS7058V]

Rationale: No further Rationale required.

4.6.7.2 System Responsiveness for Discrete Inputs

Discrete feedback delay shall be verified by test. The test will be performed with flight-configuration hardware and software, and will involve timing the delay between a discrete display input and feedback that the input was received. The verification shall be considered successful when the test indicates that the measured feedback delays are less than or equal to 0.1 seconds. [HS7058AV]

Rationale: No further Rationale required.

4.6.7.3 System Responsiveness for Continuous Inputs

Not Applicable

4.6.7.4 Request For Information

Not Applicable

4.6.7.5 Request for Critical Information

The response delay for critical displays shall be verified by test. The test shall be performed on a flight-configuration computer with a subset of mission critical displays. The test will involve requesting a mission critical display and timing the delay between the request and the presentation of the display. The verification shall be considered successful when the test shows that critical information is displayed within 1.0 second of the crew request. [HS7058DV]

Rationale: No further Rationale required.

4.6.7.6 Menu Update Time

Menu update rate shall be verified by test. The test shall be performed with flight-configuration hardware and software. The test shall consist of navigation through all menus, while timing the delay between each menu selection and the appearance of the next level of the menu. The verification shall be considered successful when the test shows that measured time between menu selection and appearance of the next menu level is less than or equal to 0.5 seconds. [HS7058EV]

Rationale: No further Rationale required.

4.6.7.7 Command Feedback

Command feedback delay shall be verified by test. The test will be performed using flight-configuration hardware and software and using a representative list of commands from a task analysis. The test will involve timing the delay between a command and feedback that the command is being processed, completed, or rejected. The verification shall be considered successful when the test shows that all delays are shown to be less than or equal to 2.0 seconds. [HS7055V]

Rationale: No further Rationale required.

4.6.8 ELECTRONIC PROCEDURES

4.6.8.1 Electronic Procedures System

The electronic procedure system shall be verified by demonstration. The demonstration shall be performed using flight-configuration hardware and software and a representative list of procedures, including those completed by crew and automation. The demonstration shall involve the simulation of tasks using the electronic procedures. The verification shall be considered successful when the demonstration shows that the procedures are displayed electronically. [HS9025V]

Rationale: No further Rationale required.

4.6.8.2 Current Procedure Step

The indication of the current procedure step shall be verified by demonstration. The demonstration shall be performed using flight-configuration hardware and software and a representative list of procedures, including those completed by crew and automation. The demonstration shall involve the simulation of the tasks using the electronic procedures. The verification shall be considered successful when the demonstration shows that the procedure display indicates the step in the procedure that is currently being executed. [HS9026V]

Rationale: No further Rationale required.

4.6.8.3 Completed Procedure Steps

The indication of the completed procedure step shall be verified by demonstration. The demonstration shall be performed using flight-configuration hardware and software and a representative list of procedures, including those completed by crew and automation. The demonstration shall involve the simulation of the tasks using the electronic procedures. The verification shall be considered successful when the demonstration shows that the procedure display indicates the step in the procedure that has been completed. [HS9027V]

Rationale: No further Rationale required.

4.6.8.4 Crew Notification of Required Procedure Action

Crew notifications of required procedural actions shall be verified by demonstration. The demonstration shall be performed using flight-configuration hardware and software and a representative list of procedures, including those completed by crew and automation. The demonstration shall involve the simulation of a task using the electronic procedures. The verification shall be considered successful when the demonstration shows that the crew was notified that attention to the procedure is required. [HS9028V]

Rationale: No further Rationale required.

4.7 MAINTENANCE AND HOUSEKEEPING

4.7.1 MAINTENANCE

4.7.1.1 Efficiency

4.7.1.1.1 ORU Changeout

The maintenance and reconfiguration tasks shall be verified by analysis. The analysis shall consist of worksite analyses for each task. The verification shall be considered successful when all replaceable or reconfigurable equipment has been shown to be removable and replaceable or reconfigured under the task constraints. [HS8001V]

Rationale: No further Rationale required.

4.7.1.1.2 Maintenance Time per Day

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 preventative 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 preventative maintenance and housekeeping can be accomplished for a mission while requiring no more than an average of two person-hours per day. [HS8002V]

Rationale: No further Rationale required.

4.7.1.1.3 ORU Maintenance Time

The number of hours for ORU maintenance shall be verified by analysis. The analysis shall consist of time studies for all ORU maintenance tasks. The verification shall be considered successful when the analysis shows that all ORU have been assessed and can be maintained within 3 hours. [HS8003V]

Rationale: No further Rationale required.

4.7.1.1.4 Access Points

Not Applicable

4.7.1.2 Error-Proof Design

4.7.1.2.1 Physical Features

The features to preclude improper mounting shall be verified by inspection. The inspection shall consist of a review of engineering drawings for hardware that is maintained or reconfigured, and that is mounted. The verification shall be considered successful when the inspection shows that the mounted hardware has features to precluding improper mounting. [HS8005V]

Rationale: No further Rationale required.

4.7.1.2.2 Labeling and Marking

The visual indication for correct equipment mounting shall be verified by inspection. The inspection shall consist of a review of engineering drawings for hard mounted equipment. The verification shall be considered successful when the inspection shows a visual indication for correct equipment mounting has been provided. [HS8006V]

Rationale: No further Rationale required.

4.7.1.2.3 Interchangeability

Hazard prevention for physically interchangeable ORUs that do not perform the same function shall be verified by inspection. The inspection shall consist of a review of the safety hazard reports for ORUs. The verification shall be considered successful when the inspection confirms that controls are in place so ORUs that are functionally different cannot be physically interchanged. [HS8007V]

Rationale: No further Rationale required.

4.7.1.2.4 Connectors

Physical features to preclude mismating and misalignment shall be by inspection, analysis, or demonstration. For the connector physical features, a demonstration consisting of mating and de-mating shall be performed for each connector type. For an integrated configuration, inspection and analysis shall be performed. The inspection shall consist of a review of the drawings for connector part numbers. An analysis shall assess the arrangement of the different types of connectors and the cable lengths.

The verification for the connector physical features shall be considered successful when the demonstration shows that the different types of connectors cannot be mismated and that within the connector type misalignment is prevented. The verification for the integrated configuration shall be considered successful with the inspection and analysis show that within connector groupings connectors cannot be mismated. [HS8008V]

Rationale: No further Rationale required.

4.7.1.2.5 Visual Indication

Orientation cues on connectors shall be verified by inspection. The inspection shall consist of reviewing each connector and its mating interface. The verification shall be considered successful when the inspection shows that there is an orientation cue that can be used prior to mating. [HS8045V]

Rationale: No further Rationale required.

4.7.1.2.6 Connector Mating Indication

Completion of connector mating shall be verified by demonstration. The demonstration shall consist of mating and demating connector types. The verification shall be considered successful when the demonstration shows that an positive indication is provided when the mating is completed. [HS8046V]

Rationale: No further Rationale required.

4.7.1.2.7 Unique Identification Labeling

Identification labeling shall be verified by inspection. The inspection shall consist of a review of engineering drawings. The verification shall be considered successful when the inspection shows that all equipment has a uniquely identifying label. [HS8047V]

Rationale: No further Rationale required.

4.7.1.3 Access

4.7.1.3.1 Disturbance of Equipment

Not applicable.

4.7.1.3.2 Access Visual

The visual access shall be verified by analysis. The analysis shall consist of worksite analyses that examine planned maintenance tasks and shows the task interfaces to be within visual access of the maintainer. The verification shall be considered successful when analysis shows that the design provides visual access for planned maintenance tasks except blind-mate connector mating. [HS8009V]

Rationale: No further Rationale required.

4.7.1.3.3 Access Physical

Work envelope for maintenance activities shall be verified by analysis. The analysis shall consist of worksite analyses for all interfaces that must be accessed to perform maintenance on each replaceable equipment item. The verification shall be considered successful when the analysis shows that all maintenance tasks can be shown to be within the access of the anthropometric range of flight crews, from work locations appropriate to the tasks, and under the environmental constraints (e.g., protective garment) of the tasks. [HS8010V]

Rationale: No further Rationale required.

4.7.1.3.4 Maintenance Hazard

Access to ORUs shall be verified by inspection. The inspection shall consist of a review of drawings and models that show the ORU location and all surrounding equipment. The verification shall be considered successful when access to ORUs can be accomplished without impacting other systems. [HS8015V]

Rationale: No further Rationale required.

4.7.1.4 Failure Notification

4.7.1.4.1 Failure Notification

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 vehicle receipt of out-of-tolerance limits. [HS8016V]

Rationale: No further Rationale required.

4.7.1.5 Circuit Protection

4.7.1.5.1 Dynamic Flight

Circuit protection shall be verified by analysis. An analysis shall determine which circuits may reset during dynamic phases of flight. The verification shall be considered successful when the analysis shows that fuses are not required to protect circuits during dynamic phases of flight. [HS8017V]

Rationale: No further Rationale required.

4.7.1.5.2 Preference

Not Applicable

4.7.1.5.3 Replacement without Tools

The removal and replacement of fuses shall be verified by inspection. The inspection shall consist of review of the engineering drawings for all equipment that contain in-flight replaceable fuses. The verification shall be considered successful when the inspection shows that fuses can be removed and replaced without a tool. [HS8020V]

Rationale: No further Rationale required.

4.7.1.5.4 Replacement without Component Removal

The removal and replacement of fuses in-flight shall be verified by inspection. The removal and replacement of fuses shall be verified by inspection. The inspection shall consist of a review of drawings or models for equipment with in-flight maintenance that contain fuses. Verification shall be considered successful when the inspection shows that each fuse can be removed and replaced without the removal of other components. [HS8021V]

Rationale: No further Rationale required.

4.7.1.5.5 Circuit Breaker Resetting

The access to reset circuit breakers by a restrained suited crewmember shall be verified by analysis and inspection. An analysis shall determine the circuit breakers the crewmembers need to reach during ascent and entry. The inspection shall consist of a review of drawings or models for the integrated circuit breakers. The verification shall be considered successful when the analysis and inspection show that the crewmember can reach each identified circuit breakers during dynamic flight phases without removing or opening a panel. [HS8022V]

Rationale: No further Rationale required.

4.7.1.5.6 Trip Indication

Indication of an open circuit shall be verified by inspection. The inspection shall consist of a review of the engineering drawings for hardware that uses fuses and circuit breakers. The verification shall be considered successful when the inspection shows that feedback is provided when the circuit is open. [HS8023V]

Rationale: No further Rationale required.

4.7.1.6 Electrostatic Discharge

4.7.1.6.1 Electrostatic Discharge

The labeling of "sensitive to electrostatic discharge" shall be verified by analysis and inspection. The analysis shall determine which equipment is susceptible to electrostatic discharge damage during operation or planned in-flight maintenance. The inspection shall consist of reviewing the engineering drawings for the identified hardware. The verification shall be considered successful when the inspection shows that the hardware drawings illustrate the locations for sensitive to electrostatic discharge labels for the hardware identified in the analysis. [HS8024V]

Rationale: No further Rationale required.

4.7.1.7 Fasteners

4.7.1.7.1 Fasteners Heads

Anti-cam-out heads shall be verified by analysis and inspection. The analysis shall identify on-orbit, tool-operated fasteners. The inspection shall consist of a review of the engineering drawings. The verification shall be considered successful when the analysis and inspection show that on-orbit tool-operated fasteners have a self-centering anti-cam-out head. [HS8029V]

Rationale: No further Rationale required.

4.7.1.7.2 Fasteners Number and Variety

Not Applicable

4.7.1.7.3 Captive Fasteners

The use of captive fasteners shall be verified by inspection. The inspection shall consist of a review of the drawings that contain fasteners that will be used in-flight. The verification shall be considered successful when the inspection show that each fastener to be actuated during in-flight maintenance tasks is captive. [HS8031V]

Rationale: No further Rationale required.

4.7.1.8 Fluids

4.7.1.8.1 Equipment Isolation

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. [HS8032V]

Rationale: No further Rationale required.

4.7.1.8.2 Leakage

Fluid leakage shall be verified by test. The test shall measure the amount of fluids released while connecting and disconnecting a fluid interface. The verification shall be considered successful when the test shows that amount of fluid released does not exceed levels described in JSC-20584, Spacecraft Maximum Allowable Concentrations (SMAC) for Airborne Contaminants. [HS8034V]

Rationale: No further Rationale required.

4.7.1.9 Tools

4.7.1.9.1 Common Toolset

Not applicable.

4.7.1.9.2 Tool Clearance

Tool clearance shall be verified by analysis. Tool interfaces shall be assessed and the allowance for the specified tool shall be analyzed, through the entire tool use envelope. Verification shall be considered successful when all tool interfaces have been shown to be in compliance. [HS8052V]

4.7.1.9.3 Tool Usage

Tool usage shall be verified by analysis and test. The analysis shall be performed to determine if crewmembers can operate all tools per Appendix B, Table B-17. The test shall consist of a set of tasks to test the operation and structural limit of the components. The analysis and test results shall be verified against Appendix B, Table B-17 by means of population analytical methods. The verification shall be considered successful when the analysis and test show the strength measurements have been met, and that the crewmember can physically interact and operate all tools for the on-orbit maintenance and reconfiguration tasks [HS8054V]

4.7.2 HOUSEKEEPING

4.7.2.1 Design for Cleanliness

4.7.2.1.1 Microbial Contamination

Microbial contamination shall be verified by test. The test shall collect samples on the interior surfaces. The verification shall be considered successful when the test shows that all of the sampled interior surfaces show fewer than 500 CFU per 100cm2 of microbial contamination. [HS8041V]

Rationale: No further Rationale required.

4.7.2.1.2 Fungal Contamination

Fungal contamination shall be verified by test. The test shall be conducted prelaunch. The test shall collect samples on the interior surfaces. The verification shall be considered successful when the test shows that all of the sampled interior surfaces show fewer than 10 CFU per 100cm2 of fungal contamination. [HS8042V]

Rationale: No further Rationale required.

4.7.2.1.3 Condensation Prevention on Interior Surfaces

The condensation persistence on surfaces shall be verified by analysis. The analysis shall consider crew induced metabolic loads in Appendix E table E2. The analysis shall include a thermal analysis to determine expected water on internal surfaces. The verification shall be considered successful when the analysis shows that condensation persistence is limited to 1 hour (TBR-006-0669) a day on surfaces within the internal volume during the mission. [HS8051V]

Rationale: No further Rationale required.

4.7.2.2 Air Filters

4.7.2.2.1 Replacement of Air Filters

Not Applicable.

4.8 INFORMATION MANAGEMENT

4.8.1 GENERAL

4.8.1.1 Crew Operability

The capability for crew to perform information management functions shall be verified by analysis and demonstration. The analysis shall determine the methods and tools for the crew to perform information management functions. The analysis shall show what information management functions are required to be available to the crew. The demonstration shall use flight-configuration software displays that show that each information management function, determined by a task analysis, can be performed on-board the vehicle. The verification shall be considered successful when information management functions defined by the analysis are shown to be available to the crew. [HS9021V]

Rationale: No further Rationale required.

4.8.2 DATA AVAILABLE

4.8.2.1 Data Rate

Not applicable.

4.8.2.2 Data Fidelity

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. [HS9040V]

Rationale: The data necessary for proper performance of all crew and ground personnel tasks for a given mission shall be determined by a task analysis.

4.8.3 DATA DISTRIBUTION

4.8.3.1 Locations

The workstation data availability shall be verified by demonstration. A task analysis shall determine what tasks will be performed on a given workstation and the data required to perform those tasks. The demonstration shall be performed on flight-configuration workstations and software. The verification shall be considered successful when the demonstration shows that all data required at a particular workstation are available at that workstation. [HS9018V]

Rationale: The data necessary for proper performance of all crew and Mission Systems personnel tasks for a given workstation shall be determined by a task analysis.

4.8.3.2 Wired Network

The vehicle's wired data distribution system shall be verified by analysis and demonstration. The analysis shall identify the required wired locations including a review of operational criticality. The demonstration shall be performed using simulated data streams with flight-configuration software loads and flight-configuration hardware. The verification shall be considered successful when the demonstration shows that vehicle data can be distributed through the wired data network to the locations defined by the analysis. [HS9019V]

Rationale: The analysis will determine what data will go to what location.

4.8.3.3 Wireless Network

The vehicle's wireless data distribution system shall be verified by analysis and demonstration. The analysis shall identify the required wireless locations including a review of operational criticality. The demonstration shall be performed using simulated data streams with flight-configuration software loads and flight-configuration hardware. The verification shall be considered successful when the demonstration shows that vehicle data can be distributed through the wireless data network to the locations defined by the analysis. [HS9020V]

Rationale: The analysis will determine what data will go to what location.

4.8.4 DATA BACKUP

4.8.4.1 Automated Backup

The ability of the vehicle to automatically back up safety critical flight data shall be verified by demonstration. A task analysis will be performed to identify what is considered safety critical data. The demonstration shall be performed on a flight-configuration computer using simulated data files and flight-configuration software loads. The verification shall be considered successful when the demonstration shows the back up proceeds automatically and the specified data are present in the backup storage location. [HS9023V]

Rationale: No further Rationale required.

4.8.4.2 Manual Backup

The ability of the vehicle to back up data shall be verified by demonstration. The demonstration shall be performed by requesting a data backup on a flight-configuration computer using simulated data files and flight-configuration software loads. The verification shall be considered successful when the demonstration shows the selected files are present in the backup storage location. [HS9041V]

Rationale: No further Rationale required.

4.8.4.3 Data Restore

The ability of the vehicle to restore data shall be verified by demonstration. The demonstration shall be performed by requesting a data restore on a flight-configuration computer using simulated data files. The verification shall be considered successful when selected files are restored from the backup storage location. [HS9042V]

Rationale: No further Rationale required.

4.8.4.4 Information Capture and Transfer

The ability to provide a method for the crew to capture and transfer information from any display in a format that provides mobility and the ability to annotate shall be verified by demonstration. The demonstration shall consist of a sample set of information being captured and transferred using flight-configuration hardware and flight software loads. The verification shall be considered successful when the demonstration produces a the desired information that can be mobile and have the ability to annotate. [HS9024AV]

Rationale: No further Rationale required.

4.9 GROUND MAINTENANCE AND ASSEMBLY

4.9.1 GROUND ANTHROPOMETRY, BIOMECHANICS, AND STRENGTH

4.9.1.1 Ground Processing Worksites

The provision of worksites that are sized for the anthropometric range of ground crews shall be verified by analysis. The analysis shall consist of worksite analyses for each assembly and ground maintenance task, as defined by the Vehicle Assembly and Ground Maintenance Task Analysis. The verification shall be considered successful when the analysis shows that each worksite is sized for the anthropometric range of stature for the 5^{th} to 95^{th} (TBR-0060606) percentiles of the worker population. [HS10008V]

Rationale: No further Rationale required.

4.9.2 GROUND NATURAL AND INDUCED ENVIRONMENTS

<Reserved>

4.9.3 GROUND SAFETY

4.9.3.1 Ventilation Openings

Protection of ventilation openings from inadvertent insertion of foreign objects shall be verified by analysis and inspection. The task analysis shall identify assembly and maintenance worksites. Worksite analysis shall show the reach envelope of crews during tasks, and an inspection of drawings shall be used to assure that openings within the reach envelope are protected from inadvertent insertion of tools or body parts. The verification shall be considered successful when the inspection shows that openings identified in the analysis are protected from insertion of foreign objects. [HS10027V]

Rationale: No further Rationale required.

4.9.3.2 Ground Processing Hardware Access

Protection from sharp edges shall be verified by inspection. The inspection shall examine all assembly and maintenance tasks, as identified in the Vehicle Assembly and Maintenance Task Analysis. This Task Analysis identifies all flight system equipment with which the ground crew will interact. The verification shall be considered successful when the inspection of shows that the identified areas have rounded edges or flight structure prevents access. [HS10030V]

Rationale: No further Rationale required.

4.9.3.3 Hazards Labeling

Hazard labeling shall be verified by inspection. The inspection shall identify the list of equipment that is susceptible to damage or constitutes a hazard to the ground crew. This list will include the type of hazard (ESD, chemical, pressurized fluid, etc.). The verification shall be considered successful when the inspection shows that all items on the list have been labeled with hazard information. [HS10033V]

Rationale: No further Rationale required.

4.9.4 GROUND ARCHITECTURE

4.9.4.1 Work Station Layout Interference

Not Applicable.

4.9.4.2 Work Station Layout Sequential Operations

Not Applicable.

4.9.5 GROUND CREW FUNCTIONS

<Reserved>

4.9.6 GROUND CREW INTERFACES

4.9.6.1 Labeling

Labels for ground crew interface controls and indicators shall be verified by inspection and analysis. The task analysis shall define those tasks for which there are controls or indicators. Inspection of drawings shall determine if labels have been incorporated into the design for those tasks. The verification shall be considered successful when the inspection shows that the controls and indicators identified in the analysis have been labeled. [HS10039V]

Rationale: No further rationale necessary.

4.9.6.2 Consistent Crew Interfaces

Not applicable.

4.9.6.3 Legibility

Legibility of labels and displays shall be verified by analysis. The analysis shall determine which labels and displays the ground crew will use and the associated task conditions. The verification shall be considered successful when the analysis shows that the labels and displays are legible under the task conditions. [HS10051]

Rationale: The intent of the requirement is to assure the information can be read or is otherwise legible under the task conditions. It is assumed that this will include appropriate placement and orientation of the information.

4.9.6.4 Written Text

The American English language requirement shall be verified by inspection. The inspection shall be performed on items containing text. The verification shall be considered successful when the inspection shows that all text is found to be written in the English language according to Webster's New World Dictionary of American English. [HS10052]

Rationale: No further rationale required.

4.9.6.5 Use of Color

Not applicable.

4.9.6.6 Work Envelope Volumes

Assembly and maintenance work envelope volumes shall be verified by analysis. The analysis shall consist of task and worksite analysis. The Vehicle Assembly Task Analysis and the Vehicle Maintenance Task Analysis shall be applied to determine task assumptions and constraints (e.g., SCAPE suit), and the worksite analysis shall account for constraints. Analysis shall account for the anthropometric range as applicable, the task, and the environmental constraints. The verification shall be considered successful when the analysis shows that the tasks have the needed work envelope volumes. [HS10002V]

Rationale: No further Rationale required.

4.9.6.7 Reach Envelope Volumes

Reach envelope volumes for assembly and maintenance task shall be verified by analysis. The analysis shall examine all assembly tasks, as identified in the Vehicle Assembly Task Analysis. The task analysis shall determine task assumptions and constraints (e.g., SCAPE suit), and worksite analysis shall account for constraints per FAA-HF-STD-001, Sections 14.1 through 14.5 and NASA-STD-3000 Section 3.3.3. The analysis shall also include a worksite analysis. This analysis shall account for the anthropometric range applicable, the task, and the environmental constraints. The verification shall be considered successful when the analysis shows that the reach envelope volumes needed for corrective and preventative maintenance tasks have been provided. [HS10004V]

Rationale: No further Rationale required.

4.9.6.8 Ground Crew Visual Access

Visual access shall be verified by analysis. The analysis shall examine assembly and maintenance tasks, as identified in the Vehicle Assembly Task Analysis and the Vehicle

Maintenance Task Analysis, respectively. A worksite analysis shall be performed using CAD models and human models that display field of view of the ground crew. The verification shall be considered successful when the analysis shows that the ground crew has the visual access to perform the tasks associated with vehicle maintenance. [HS10006V]

Rationale: No further Rationale required.

4.9.7 LAUNCH SITE PROCESSING AND GROUND MAINTENANCE

4.9.7.1 Line Replaceable Units (LRUs)

4.9.7.1.1 LRU Installation

Features to prevent incorrect LRU installation shall be verified by inspection. The inspection shall examine the LRU drawings and their interfaces to the vehicle for features which preclude incorrect installation. The verification shall be considered successful when the inspection shows that all LRUs have features to preclude incorrect installation. [HS10012V]

Rationale: No further Rationale required.

4.9.7.1.2 LRU Mounting/Alignment Labels/Codes

Identification for proper mounting and alignment of LRUs shall be verified by inspection. The inspection shall examine LRU drawings and their interfaces to the vehicle for labels or other coding that indicates proper installation. The verification shall be considered successful when the inspection shows that all LRUs and their interfaces have a visual indication of proper mounting and alignment. [HS10013V]

Rationale: No further Rationale required.

4.9.7.1.3 LRU Interchangeability

Non-interchangeability of LRUs shall be verified by analysis. The function of LRUs shall be determined by inspection of documentation, drawings, and diagrams. Drawings of LRUs and their interfaces shall be examined for installation and connection design. Analysis shall compare those LRUs which are determined to be functionally distinct to assure they cannot be installed in place of any other distinct unit. The verification shall be considered successful when the analysis shows that LRUs are functionally distinct replaceable units which cannot be installed in the wrong location [HS10014V]

Rationale: No further Rationale required.

4.9.7.1.4 LRU Tracking Labels

The labeling for logistics tracking shall be verified by inspection. The inspection shall review the drawings of LRUs with which the ground crew shall interact based on the maintenance tasks, as identified in the Vehicle Assembly and Maintenance Task Analysis. The verification shall be considered successful when inspection of shows that all equipment identified as LRUs have logistics tracking labels. [HS10031V]

Rationale: No further Rationale required.

4.9.7.1.5 LRU Labeling

LRU and flight component labeling shall be verified by inspection. The inspection shall examine all assembly and maintenance tasks, as identified in the Vehicle Assembly and Maintenance Critical Task Analysis. The verification shall be considered successful with the inspection shows that the items identified in the task analysis are labeled when identification information within the field of view of the ground crew. [HS10032V]

Rationale: No further Rationale required.

4.9.7.1.6 LRU Protrusions

LRU protrusions that could be used as handles shall be verified by analysis. An analysis shall determine which protrusions could be used as handles. For each identified protrusion, the associated weight which it can support will be determined. The verification shall be considered successful when the analysis shows that the identified protrusions can support the weight of the LRU without damaging or deforming the LRU. [HS10042V]

4.9.7.1.7 LRU Weight Limit

Safe lifting weight for one ground person without ground support equipment shall be verified by analysis. The analysis shall determine the safe lifting weight per the NIOSH lifting equation for the LRUs identified in the Ground Maintenance Task Analysis that require one person installation without ground support equipment. The verification shall be considered successful with the analysis shows that the identified LRUs do not exceed the safe lifting weight for one ground crewperson. [HS10045V]

4.9.7.1.8 LRU Removal without Component Removal

Not applicable.

4.9.7.1.9 LRU Removal and Replacement

Not Applicable.

4.9.7.2 Connectors

4.9.7.2.1 Connector Mismating

Prevention for mismating connectors within the same physical location shall be verified by analysis and inspection. The analysis shall identify which connector plugs might possibly be mated to which jacks and the cable lengths associated with each connector. The inspection shall review all drawings for the connector assemblies identified by the analysis that could be possibly mated. The verification shall be considered successful when the analysis and inspection show that connectors within the same physical location cannot be physically mismated. [HS10015V]

Rationale: No further Rationale required.

4.9.7.2.2 Connector Mating Labels

Connector mating labels shall be verified be by inspection. The inspection shall consist of a review of engineering drawings that contain the connectors to be mated during launch site processing. The verification shall be considered successful when the inspection shows that the connectors within the same physical location have labels that define correct mating. [HS10017V]

Rationale: No further Rationale required.

4.9.7.3 Fasteners

4.9.7.3.1 Captive Fasteners

Not applicable.

4.9.7.4 Tools

4.9.7.4.1 Toolset

Tools used for assembly and maintenance shall be verified by analysis. The Vehicle Assembly Task Analysis and the Vehicle Maintenance Task Analysis will identify those tasks requiring tools and the tool for the task. The analysis will compare the identified tools with the Launch Site Task Tool List, Table 3.9-1 (TBD-006-050). The verification shall be considered successful when the analysis shows that all tools used for maintenance and assembly are on the tool list. [HS10028V]

Rationale: No further Rationale required.

4.9.7.4.2 Tool Clearances

Tool clearances for assembly, launch site processing, and corrective and preventative maintenance at the launch site shall be verified by analysis. The Vehicle Assembly Task Analysis and the Vehicle Maintenance Task Analysis will identify those tasks requiring tools and the tool for the task. The verification shall be considered successful when the analysis shows that all tool interfaces have the clearance needed for installation and actuation. [HS10024V]

Rationale: No further Rationale required.

4.9.7.5 Circuit Protection

4.9.7.5.1 Fuse/Circuit Indication

Indication of an open circuit shall be by inspection. Drawings shall be inspected for devices that contain a fuse or circuit breaker. The verification shall be considered successful when the inspection shows that each drawing identifying circuit protection devices has a callout that specifies the parts are designed to provide a positive indication of an open circuit. [HS10010V]

Rationale: No further Rationale required.

4.9.7.6 Access

4.9.7.6.1 Maintainability without Deintegration

Maintainability without deintegration of elements and subsystems shall be verified by analysis and demonstration. The analysis shall examine all scheduled or preventative ground maintenance tasks, as identified in the Vehicle Maintenance Task Analysis. Worksite analysis for each task shall evaluate the need to deintegrate systems for each of the defined tasks. A demonstration of the maintenance task shall be performed only for tasks require two or more personnel. The verification shall be considered successful when the analysis and demonstration show that maintenance tasks can be completed without deintegration of components. [HS10001V]

Rationale: The Vehicle Maintenance Task Analysis is a complete listing of all tasks associated with vehicle maintenance (includes, e.g., bolt insertion, bolt torquing, connector *mating, et c.). This task analysis becomes a deliverable product that is the basis of procedures development. Worksite analysis is typically a CAD-based assessment of task feasibility, using human models. Simple measurement may be accomplished by drawing inspection.*

4.9.7.6.2 Maintainability without Disabling Subsystems

Not applicable.

4.9.7.6.3 Appropriate Clothing

Accommodation for ground crews wearing protective clothing and equipment shall be verified by analysis. The analysis shall consist of worksite analyses for each assembly task, as defined by the Vehicle Assembly Task Analysis. Task analysis shall identify those tasks which require protective equipment for assembly. Worksite analysis shall assess task feasibility under the constraints of protective equipment. The verification shall be considered successful when the analysis shows that tasks requiring protective clothing and/or equipment can be accommodated within the worksite. [HS10011V]

Rationale: No further Rationale required.

4.9.7.6.4 Inspection Access

Accessibility for component inspection during launch site processing shall be verified by analysis. The analysis shall identify components required to be inspected during launch site processing. An accessibility analysis shall be completed for each identified component. The verification shall be considered successful when the analysis shows that each component requiring inspection can be accessed. [HS10025V]

Rationale: No further Rationale required.

4.9.7.6.5 Cable Access

Cable accessibility shall be verified by analysis. The maintenance and inspection task list will identify those cables requiring inspection. The analysis shall consist of an assessment of the visibility and reach access to cables for ground operations. The verification shall be considered successful when the analysis shows that the ground crew can gain access to all cables. [HS8011V]

Rationale: No further Rationale required.

4.9.7.6.6 External Service Points

The external service point locations shall be verified by inspection. The inspection shall consists of a review of drawings or models of the external service points and their location in relation to the service structure. The verification shall be considered successful when the inspection shows all service points are within 60 degrees, radially, of the plane between the vehicle and service structure. [HS8013V]

Rationale: No further Rationale required.

4.9.7.6.7 Visual-Line-of-Sight

Not applicable.

4.9.7.7 Damage/Hazard Controls

4.9.7.7.1 Equipment Labels and Codes for Hazards

Hazard labeling or coding for equipment to be accessed by the ground crew shall be verified by inspection. The inspection shall determine the list of equipment requiring hazard labels or coding. The verification shall be considered successful when the inspection shows that all identified equipment has a hazard label or code. [HS10018V]

Rationale: No further Rationale required.

4.9.7.7.2 Maintenance without Damange

Protection for component during scheduled or preventative maintenance shall be verified by analysis. The task analysis shall identify all scheduled or preventative maintenance tasks. The analysis shall examine drawings and models for each area and the surrounding equipment. The verification shall be considered successful when the analysis shows that all maintenance activities associated with one component does not result in damage of other in-place and certified components. [HS10019V]

Rationale: No further Rationale required.

4.9.7.7.3 Isolation Valves

Isolation of pressurized fluids during launch site processing and ground maintenance shall be verified by analysis. The Vehicle Assembly Task Analysis and the Vehicle Maintenance Task Analysis shall identify those systems containing pressurized fluids. The verification shall be considered successful when the analysis shows that all subsystems with pressured fluids that require ground crew intervention have isolation features. [HS10020V]

Rationale: No further Rationale required.

4.9.7.7.4 Fluid Spillage Control

Controls for fluid release during launch site processing shall be verified by inspection. The inspection shall review drawings and other documentation for controls that provide methods of limiting ground crew exposure to fluid spillage. The verification shall be considered successful when the inspection shows that design for assembly and maintenance tasks includes controls for spillage and fluid release. [HS10021V]

Rationale: No further Rationale required.

4.9.7.7.5 System Safing Controls

Controls to safe the system prior to maintenance shall be verified by inspection. The inspection drawings and other documentation shall identify controls that provide methods of system safing. The verification shall be considered successful when the inspection shows that controls for safing the system have been provided for assembly and maintenance tasks. [HS10022V]

Rationale: No further Rationale required.

4.9.7.7.6 Equipment Protection

Not applicable.

4.9.7.7.7 Safety Displays

Display placement for tasks that could result in a hazard shall be verified by analysis. Task analysis shall determine which tasks require operator views of displays for successful task completion. Worksite analysis shall evaluate the position of the display while the task is being performed. The verification shall be considered successful when the analysis shows that all tasks requiring visual access to displays are within the field of view of the personnel performing the task. [HS10029V]

Rationale: No further Rationale required.

4.9.7.7.8 Protrusion Label/Support

Protrusions that could be used as handles, steps, or hand rails shall be verified by analysis. The analysis shall determine which protrusions could be used for handles, steps, or hand rails. The verification shall be considered successful when the analysis shows that the identified protrusions can support the weight of personnel or are clearly labeled as a Keep Out Zone. [HS10043V]

4.9.8 GROUND INFORMATION MANAGEMENT

<Reserved>

Appendix A - Bibliography

Chesnin, M.P. (1996). Fourteen segment geometric-based multiple linear regression model for calculating segment masses. Presented at the American Society of Biomechanics 20th Annual Meeting at Georgia Institute of Technology, Atlanta, GA.

Gehan, E.A., George, S.L. (1970). Estimation of human body surface area from height and weight. Cancer Chemotherapy Reports Part I, 54(4), 225-235.

Gordon, C.C., Churchhill, T., Clauser, C.E., Brandtmiller, B., McConville, J.T., Tebbetts, I., Walker, R.A. (1989). 1988 Anthropometric survey of U.S. army personnel: methods and summary statistics. NATICK/TR-89/044, United States Army Natick Research, Development and Engineering Center, Massachusetts.

McConville, J.T., Churchill, T.D., Kaleps, I., Cuzzi, J., (1980). Anthropometric relationships of body and body segment moments of inertia. AFAMRL-TR-80-119, Wright-Patterson Air Force Base, Ohio.

Young, J.W., Chandler, R.F., Snow, C.C., Robinette, K.M., Zenner, G.F., Lofberg, M.S. (1983). Anthropometrics and mass distribution characteristics of the adult female. FAA-AM-83-16, Revised Edition, FAA Civil Aeromedical Institute, Oklahoma City, Oklahoma.

Ogden, C.L., Fryar, C.D., M.S.P.H., Carroll, M.D., Flegal, K. M. (2004). Mean body weight, height, and body mass index, United States 1960–2002, U.S. Department of Health and Human Services.

Churchill, Kikta, and Churchill. Intercorrelations of Anthropometric Measurements. TR77-1 Aerospace Medical Research Laboratory, Wright Patterson Air Force Base, Ohio.

Tillman, B., McConville, J. (1991). Year 2015 astronaut population anthropometric calculations for NASA-STD-300.

Chaffin, D. B., Occupation Biomechanics, Second Edition, John Wiley & Sons, Inc., 1991

Mil-Std-1472, Rev F, Department of Defense Design Criteria Standard (1999)

Appendix B - Anthropometry, Biomechanics, and Strength

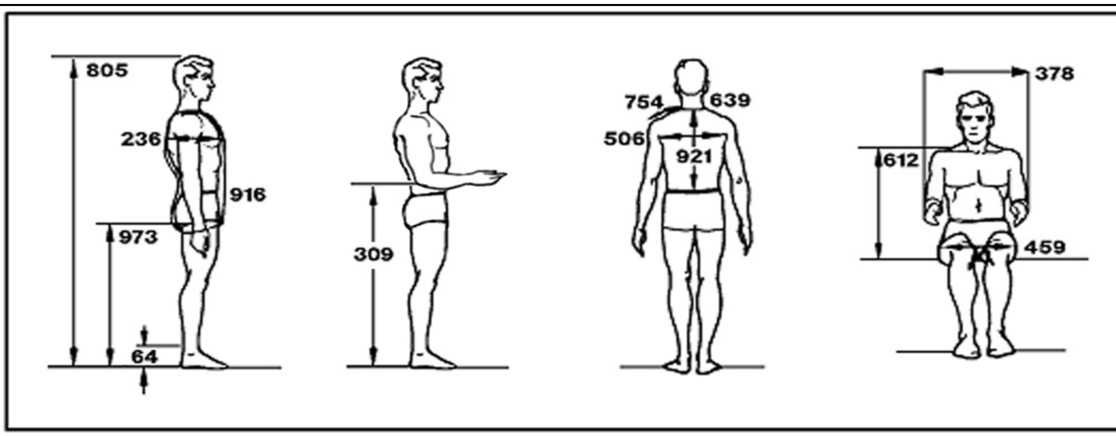
B1 Anthropometry

The data in this section are from the population in the 1988 Anthropometric Survey of US Army Personnel (or ANSUR) (ref. Natick/TR-89/044), projected forward by NASA to 2015 to account for the expected small growth in the size of members of the US population. The anthropometric limits represent 1st (TBR-006-2002) and 99th (TBR-006-2003) percentile values of the female and male data (unless otherwise noted in the tables), respectively.

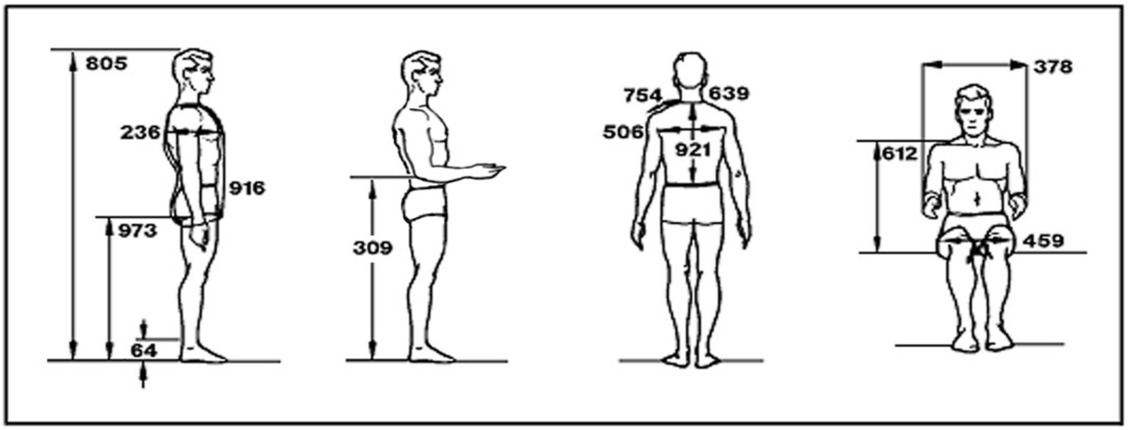
Note that for measurements that include the length of the spine, 3% of stature must be added to allow for spinal elongation due to micro-gravity exposure.

Tables B1 through B6 contain data range for general anthropometric dimensions under minimally clothed condition. Specific anthropometric dimensions that are unique to Constellation vehicle operations are provided in Table B7-A. Specific anthropometric dimensions that are critical for designing the space suits are provided in Table B7-B. Tables B7-A and B7-B contain anthropometric data range not only for minimally clothed condition but also for suited (un-pressurized and pressurized) conditions. Users are advised to use the data appropriately. It should be noted that the suit dependent data were derived by calculating the deltas in measurements between suited and unsuited conditions from a select sample of test subjects. It should also be noted that the test involved using the ACES type suit.

Table B-1 Anthropometric Dimensional Data for American Female and Male (TBR-006-030)



No.	Dimension	Min (cm, (in))	Max (cm, (in))
805	Stature	143.3 (58.5)	194.6 (76.6)
973	Wrist height	67.9 (27.7)	96.3 (37.9)
64	Ankle height	4.7(1.9)	8.1 (3.2)
309	Elbow height (rest height standing)	86.7 (35.4)	120.7 (47.5)
236	Bust depth (chest depth)	18.4 (7.5)	30.2 (11.9)
916	Vertical trunk circumference	130.1 (53.1)	181.9 (71.6)
612	Mid-shoulder height, sitting	50.7 (20.7)	71.1 (28.0)

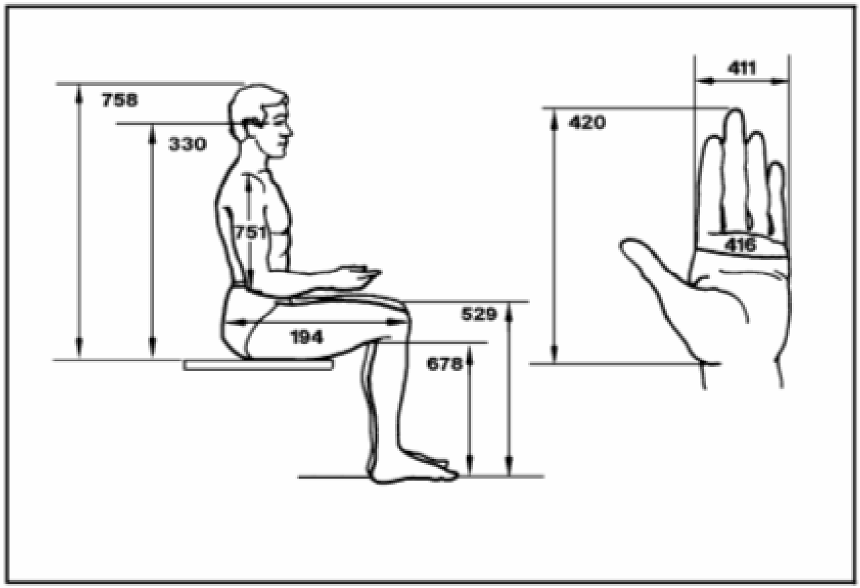


No.	Dimension	Min (cm, (in))	Max (cm, (in))
459*	Hip breadth, sitting	30.4 (12.4)	46.5 (18.3)
921	Waist back	37.7 (15.4)	55.9 (22.0)
506	Interscye	28.2 (11.5)	48.0 (18.9)
639	Neck circumference	26.7 (10.9)	43.4 (17.1)
754	Shoulder length (side neck-to-acromion horizontal distance)	11.5 (4.7)	18.0 (7.1)
378	Forearm-forearm breadth	37.5 (15.3)	66.0 (26.0)

*For seated measurements, the largest female hip breadth is larger than the largest male hip breadth, and the smallest male hip breadth is smaller than the smallest female hip breadth; therefore, male data is used for the Min dimension, and female data is used for the Max dimension.

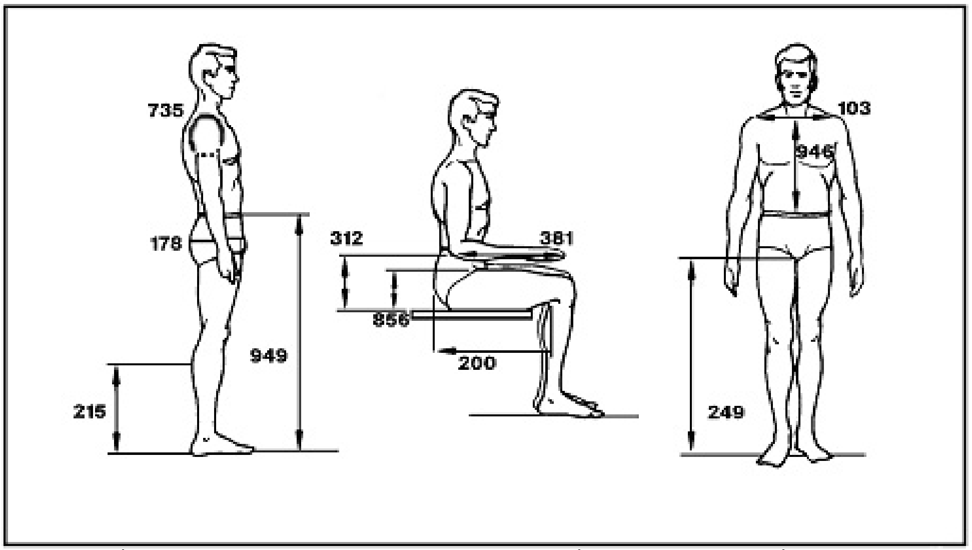
Table B-2 Anthropometric Dimensional Data for American Female and Male (TBR-006-

030)



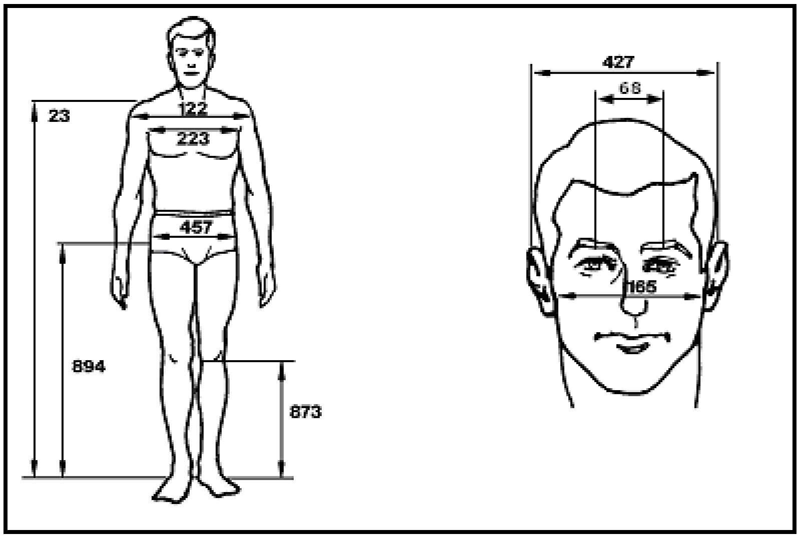
No.	Dimension	Min (cm, (in))	Max (cm, (in))
758	Sitting height	75.0 (30.6)	101.3 (39.9)
330	Eye height, sitting	64.2 (26.2)	88.9 (35.0)
529	Knee height, sitting	43.9 (17.9)	63.5 (25.0)
678	Popliteal height	31.9 (13.0)	50.0 (19.7)
751	Shoulder-elbow length	28.4 (11.6)	41.9 (16.5)
194	Buttock-knee length	50.2 (20.5)	69.9 (27.5)
420	Hand length	15.2 (6.2)	22.1 (8.7)
411	Hand breadth	6.9 (2.8)	10.2 (4.0)
416	Hand circumference	16.2 (6.6)	24.1 (9.5)

Table B-3 Anthropometric Dimensional Data for American Female and Male (TBR-006-030)



No.	Dimension	Min (cm, (in))	Max (cm, (in))
949	Waist height	83.5 (34.1)	119.6 (47.1)
249	Crotch height	64.2 (26.2)	95.8 (37.7)
215	Calf height	25.0 (10.2)	41.4 (16.3)
103	Biacromial breadth	31.1 (12.7)	44.5 (17.5)
946	Waist front	32.8 (13.4)	48.8 (19.2)
735	Scye circumference	30.9 (12.6)	52.1 (20.5)
178	Buttock circumference	81.1 (33.1)	114.8 (45.2)
312	Elbow rest height	15.7 (6.4)	30.0 (11.8)
856	Thigh clearance	12.5 (5.1)	20.1 (7.9)
381	Forearm hand length	37.2 (15.2)	54.6 (21.5)
200	Buttock-popliteal length	40.7 (16.6)	57.2 (22.5)

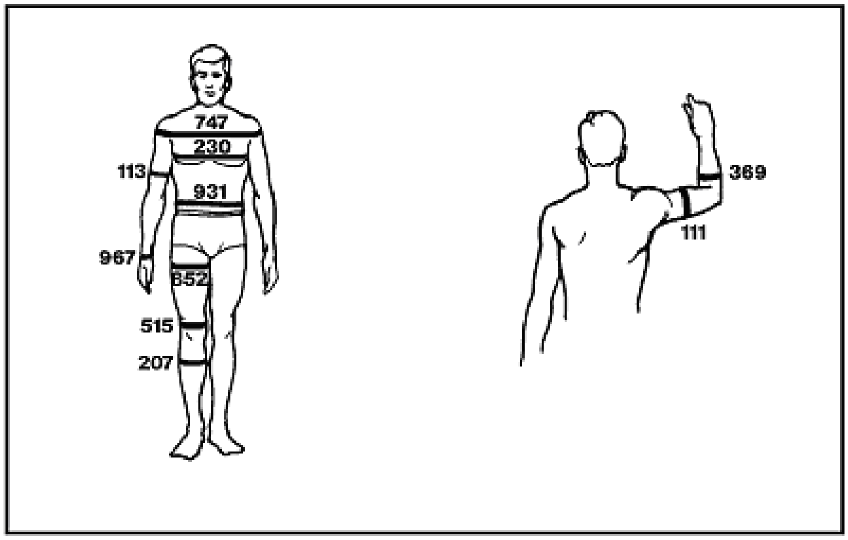
Table B-4 Anthropometric Dimensional Data for American Female and Male (TBR-006-030)



No.	Dimension	Min (cm, (in))	Max (cm, (in))
23	Acromial (shoulder) height	116.1 (47.4)	161.8 (63.7)
894	Trochanteric height	72.5 (29.6)	105.4 (41.5)
873	Knee Height, Midpatella	38.2 (15.6)	57.9 (22.8)
122	Bideltoid (shoulder) breadth	36.5 (14.9)	56.1 (22.1)
223	Chest breadth	22.8 (9.3)	39.4 (15.5)
457*	Hip breadth	28.7 (11.7)	40.6 (16.0)
165	Bizgomatic (face) breadth	11.5 (4.7)	15.5 (6.1)
427	Head breadth	12.7 (5.2)	16.5 (6.5)
68	Interpupillary Breadth	5.1 (2.1)	7.4 (2.9)

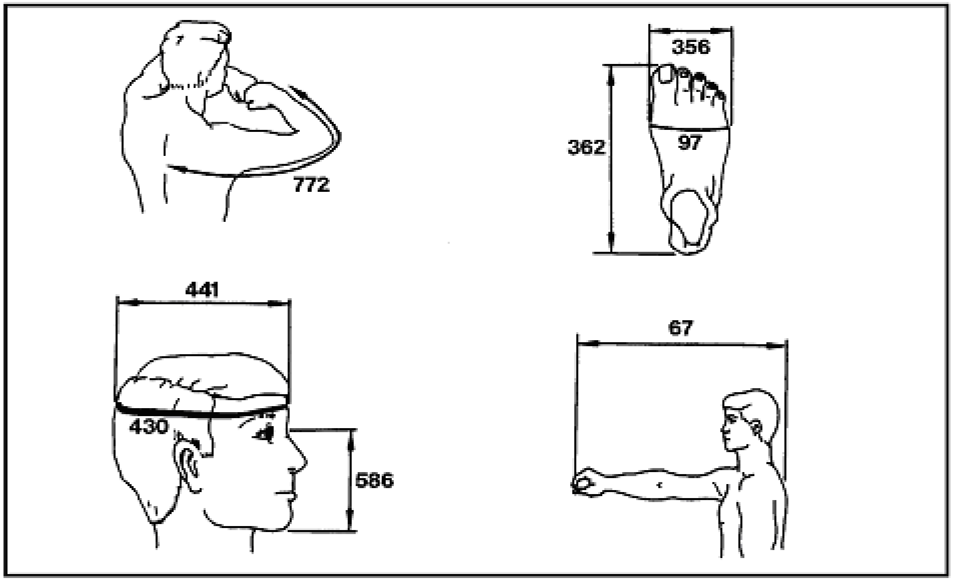
*For standing measurements, the largest female hip breadth is larger than the largest male hip breadth; therefore, female data is used for both the Min dimension and the Max dimension.

Table B-5 Anthropometric Dimensional Data for American Female and Male (TBR-006-030)



No.	Dimension	Min (cm, (in))	Max (cm, (in))
747	Shoulder circumference	90.4 (35.6)	133.9 (133.9)
230	Chest circumference	75.7 (29.8)	118.6 (46.7)
931	Waist circumference	61.2 (24.1)	110.5 (43.5)
852	Thigh circumference	47.8 (18.8)	71.9 (28.3)
515	Knee circumference	30.7 (12.1)	44.5 (17.5)
207	Calf circumference	29.5 (11.6)	44.5 (17.5)
967	Wrist circumference	13.5 (5.3)	19.8 (7.8)
111	Biceps circumference, flexed	22.9 (9.0)	40.4 (15.9)
369	Forearm circumference, flexed	21.6 (8.5)	35.3 (13.9)

Table B-6 Anthropometric Dimensional Data for American Female and Male (TBR-006-030)

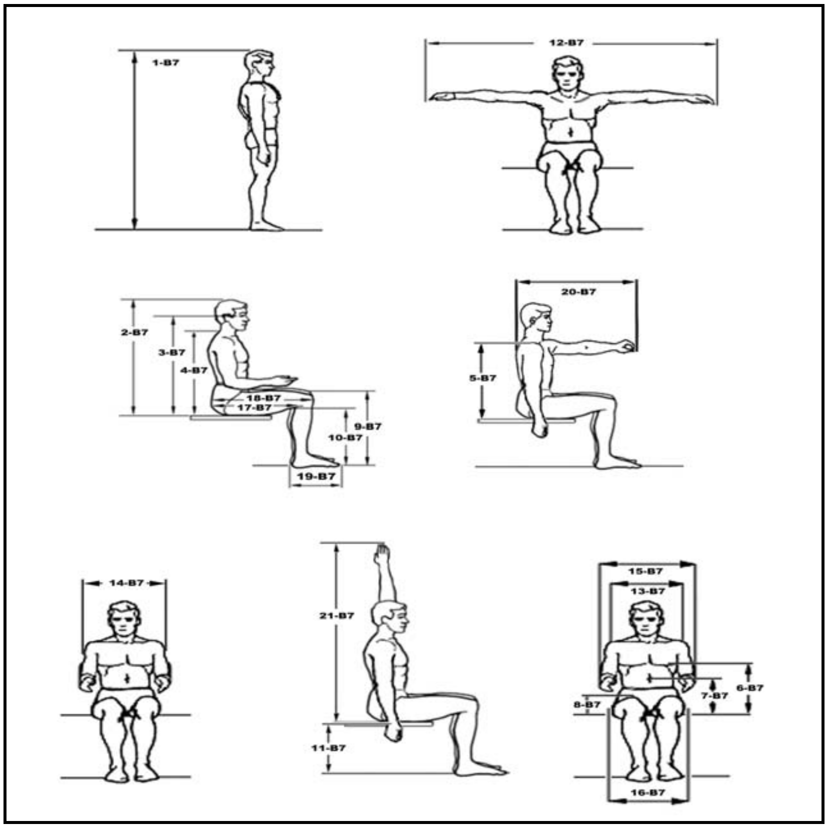


No.	Dimension	Min (cm, (in))	Max (cm, (in))
67	Thumb-tip reach	65.0 (25.6)	90.9 (35.8)
772	Sleeve length	72.4 (28.5)	99.1 (39.0)
441	Head length	17.3 (6.8)	21.6 (8.5)
430	Head circumference	51.3 (20.2)	61.0 (24.0)
586	Menton-sellion (face) length	9.9 (3.9)	14.0 (5.5)
362	Foot length	21.6 (8.5)	30.5 (12.0)
356	Foot breadth	7.9 (3.1)	11.4 (4.5)
97	Ball of foot circumference	19.6 (7.7)	28.2 (11.1)

Table B-7A Vehicle Design Critical Anthropometry Dimensions (TBR-006-002)

Design Concern	Critical Dimension	Minimal Clothing		With ACES-type Suit, Unpressurized		With ACES-type Suit, Pressurized	
		Min (cm, (in))	Max (cm, (in))	Min (cm, (in))	Max (cm, (in))	Min (cm, (in))	Max (cm, (in))
Maximum vertical clearance	Stature, Standing [1-B7]	148.6 (58.5)	194.6 (76.6)	157.7 (62.1)	203.7 (80.2)	158.0 (62.2)	200.2 (78.8)
Vertical seating clearance	Sitting Height [2-B7]	77.7 (30.6)	101.3 (39.9)	83.6 (32.9)	112.8 (44.4)	85.9 (33.8)	110.7 (43.6)
Placement of panels to be within line-of-sight	Eye Height, Sitting [3-B7]	66.5 (26.2)	88.9 (35.0)	61.2 (24.1)	87.6 (34.5)	56.9 (22.4)	84.8 (33.4)
Placement of headrest	Cervicale Height, Sitting [4-B7]	56.6 (22.3)	76.2 (30.0)	58.9 (23.2)	81.5 (32.1)	59.7 (23.5)	78.2 (30.8)
Top of seatback	Acromial Height, Sitting [5-B7]	49.5 (19.5)	68.1 (26.8)	48.8 (19.2)	68.8 (27.1)	48.3 (19.0)	68.3 (26.9)
Placement of restraints	Chest Height, Sitting [6-B7]	33.8 (13.3)	50.3 (19.8)	32.5 (12.8)	48.3 (19.0)	31.8 (12.5)	47.2 (18.6)
Placement of restraining straps	Waist Height, Sitting (Omphalion) [7-B7]	19.3 (7.6)	27.2 (10.7)	17.8 (7.0)	29.5 (11.6)	18.8 (7.4)	29.5 (11.6)
Placement of objects which may be over lap (panels, control wheel, etc.)	Thigh Clearance, Sitting [8-B7]	13.0 (5.1)	20.1 (7.9)	15.0 (5.9)	19.8 (7.8)	17.5 (6.9)	21.6 (8.5)
Height of panels in front of subject	Knee Height, Sitting [9-B7]	45.5 (17.9)	63.5 (25.0)	47.2 (18.6)	66.3 (26.1)	51.3 (20.2)	69.9 (27.5)
Height of seat pan	Popliteal Height, Sitting [10-B7]	33.0 (13.0)	50.0 (19.7)	31.8 (12.5)	51.1 (20.1)	32.0(12.6)	49.0 (19.3)
Downward reach of subject	Wrist Height, Sitting (with arm to the side) [11-B7]	39.6 (15.6)	54.6 (21.5)	41.1 (16.2)	62.5 (24.6)	45.0 (17.7)	63.5 (25.0)
Side envelope – maximum lateral reach	Span, Sitting [12-B7]	147.8 (58.2)	204.7 (80.6)	147.6 (58.1)	210.6 (82.9)	142.7 (56.2)	207.5 (81.7)
Placement of restraint straps	Biacromial Breadth [13-B7]	32.3 (12.7)	44.5 (17.5)	36.1 (14.2)	45.5 (17.9)	34.8 (13.7)	47.8 (18.8)

Design Concern	**Critical Dimension**	**Minimal Clothing**		**With ACES-type Suit, Unpressurized**		**With ACES-type Suit, Pressurized**	
		Min (cm, (in))	**Max (cm, (in))**	**Min (cm, (in))**	**Max (cm, (in))**	**Min (cm, (in))**	**Max (cm, (in))**
Width of seatback	Bideltoid Breadth [14-B7]	37.8 (14.9)	56.1 (22.1)	53.1 (20.9)	66.3 (26.1)	58.4 (23.0)	70.9 (27.9)
Side clearance envelope, possible seatback width	Forearm-Forearm Breadth [15-B7]	38.9 (15.3)	66.0 (26.0)	69.3 (27.3)	87.6 (34.5)	82.3 (32.4)	100.6 (39.6)
Width of seat pan	Hip Breadth, Sitting [16-B7]*	31.5 (12.4)	46.5 (18.3)	36.3 (14.3)	54.4 (21.4)	38.9 (15.3)	55.6 (21.9)
Length of seat pan	Buttock-Popliteal Length, Sitting [17-B7]	42.2 (16.6)	57.2 (22.5)	47.2 (18.6)	62.2 (24.5)	50.0 (19.7)	68.6 (27.0)
Placement of panels in front of subject	Buttock-Knee Length, Sitting [18-B7]	52.1 (20.5)	69.9 (27.5)	59.9 (23.6)	73.9 (29.1)	66.3 (26.1)	82.0 (32.3)
Rudder pedal design, foot clearance	Foot Length, Sitting [19-B7]	21.6 (8.5)	30.5 (12.0)	27.2 (10.7)	38.6 (15.2)	27.2 (10.7)	38.6 (15.2)
Placement of control panels, maximum reach	Thumbtip Reach, Sitting [20-B7]	65.0 (25.6)	90.9 (35.8)	67.3 (26.5)	103.1 (40.6)	52.8 (20.8)	100.6 (39.6)
Maximum vertical reach for controls	Vertical Index Fingertip Reach, Sitting [21-B7]	118.9 (46.8)	158.2 (62.3)	96.3 (37.9)	136.1 (53.6)	71.9 (28.3)	116.6 (45.9)



1-B7
12-B7
2-B7
3-B7
4-B7
18-B7
17-B7
9-B7
10-B7
19-B7
20-B7
5-B7
14-B7
21-B7
11-B7
15-B7
13-B7
6-B7
7-B7
8-B7
16-B7

Table B-7B Suit Design Critical Anthropometry Dimensions (TBR-006-002)

Design Concern	Critical Dimension	Minimal Clothing	
		Min (cm, (in))	Max (cm, (in))
Maximum vertical clearance	Stature, Standing [1-B7]	148. 6 (58.5)	194.6 (76.6)
Placement of headrest	Vertical Trunk Diameter[22 – B7]	55.9 (22.0)	75.9 (29.9)
Leg length	Crotch height [249-B3]	66.5 (26.2)	95.8 (37.7)
Knee break	Knee height mid-patella [873-B4]	39.6 (15.6)	57.9 (22.8)
Torso sizing	Chest breadth [223-B4]	23.6 (9.3)	39.4 (15.5)
Neck ring and helmet sizing	Head breadth [427-B4]	13.2 (5.2)	16.5 (6.5)
Torso sizing	Chest depth [236-B1]	19.1 (7.5)	30.2 (11.9)
Neck ring and helmet sizing	Head length [441-B6]	17.3 (6.8)	21.6 (8.5)
Maximum circumference of upper leg	Thigh circumference [852-B5]	47.8 (18.8)	71.9 (28.3)
Maximum circumference of upper arm	Biceps circumference flexed [111-B6]	22.9 (9.0)	40.4 (15.9)
Torso sizing	Chest circumference [230-B5]	75.7 (29.8)	118.6 (46.7)
Arm sizing	Inter-wrist distance [24-B7]	115.1 (45.3)	161.8 (63.7)
Functional arm break, arm length	Inter-elbow distance [25-B7]	72.6 (28.6)	101.3 (39.9)
Lower torso sizing	Waist depth [26-B7]	15.0 (5.9)	30.0 (11.8)
Lower torso sizing	Hip breadth [27-B7]	29.7 (11.7)	40.6 (16.0)
Arm sizing	Wrist-to-wall distance [28-B7]	54.6 (21.5)	77.7 (30.6)

B2 Range of Motion

The range of crewmember motion and reach to be accommodated (shown in Tables B-8 through B-10) were collected in 1-gravity under 'shirt-sleeve' conditions. The data applies to unsuited one G through zero G conditions.

Data in Tables B-9 and B-10 provide multi-joint functional ranges of motion associated with tasks that a vehicle crewmember may be called upon to perform. Figure B-1 shows the planes and axes for the joint angle ranges given in these two tables.

Table B-8 Joint Movement Ranges for Males and Females

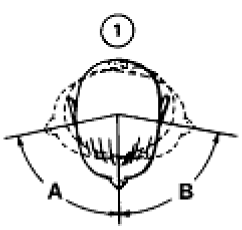
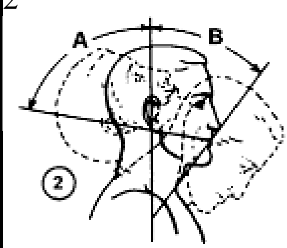
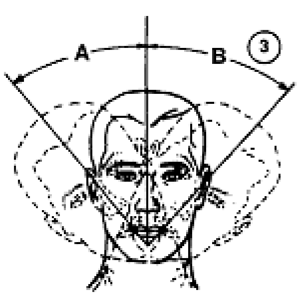
Figure	Joint movement	Range of motion (degrees)
1  Neck Rotation Right (A) Left (B)	Neck, rotation right (A)	73
	Neck, rotation left (B)	72
2  Neck Extension [A] Flexion (B)	Neck, extension (A)	34
	Neck, flexion (B)	65
3  Neck Lateral Bend Right (A) Left (B)	Neck, lateral bend right (A)	35
	Neck, lateral bend left (B)	29

Table B-8 Joint Movement Ranges for Males and Females (cont.)

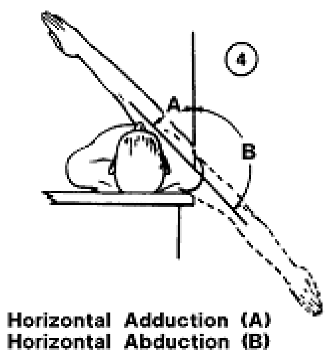
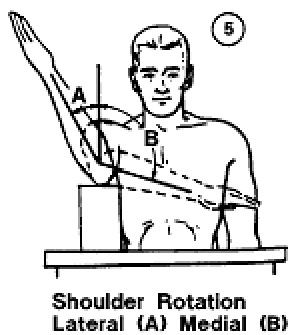
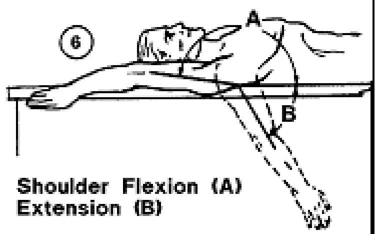
Figure	Joint movement	Range of motion (degrees)
4 	**Shoulder**, abduction (B) **Shoulder**, adduction (A)	135* 45*
5 	**Shoulder**, rotation lateral (A) **Shoulder**, rotation medial (B)	46 91
6 	**Shoulder**, flexion (A) **Shoulder**, extension (B)	152 33

Table B-8 Joint Movement Ranges for Males and Females (cont.)

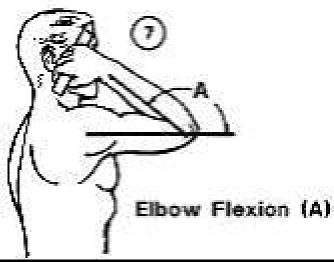
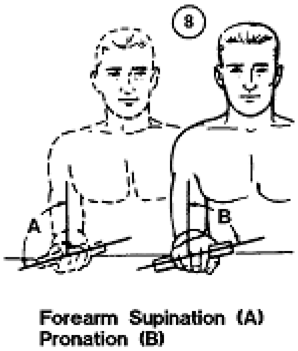
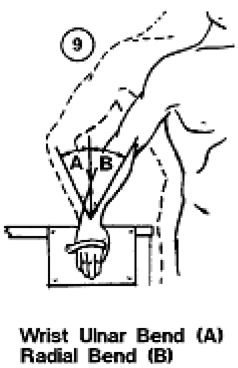
Figure	Joint movement	Range of motion (degrees)
7 	Elbow, Flexion (A)	141
8 	Forearm, supination (A) Forearm, pronation (B)	83 78
9 	Wrist, ulnar bend (A) Wrist, radial bend (B)	19 16

Table B-8 Joint Movement Ranges for Males and Females (cont.)

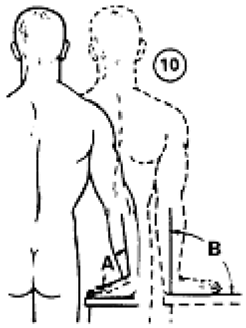
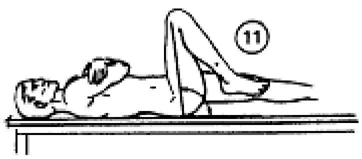
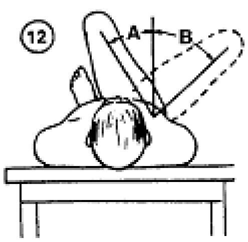
Figure	Joint movement	Range of motion (degrees)
10  Wrist Flexion (A) Extension (B)	Wrist, flexion (A) Wrist, extension (B)	62 40
11  Hip Flexion	Hip, flexion	117
12  Hip Adduction (A) Abduction (B)	Hip, adduction (A) Hip, abduction (B)	30 35

Table B-8 Joint Movement Ranges for Males and Females (cont.)

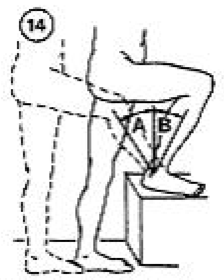
Figure	Joint movement	Range of motion (degrees)
13 	Knee, flexion	118
14 	Ankle, plantar extension (A) Ankle, dorsi flexion (B)	36 7
* Indicates data was missing or unclear and substituted with range of motion calculations from other sources.		

Table B-9 Minimum Joint Range of Motion to Perform Selected Functional Tasks of the Upper Body (TBR-006-069)

Shoulder Flexion (+) / Extension (-) $\{Z_4\}$	Shoulder Abduction (+)/ Adduction (-) $\{Y_4\}$	Shoulder External (+) / Internal (-) Rotation $\{X_4\}$	Elbow Flexion (+) $\{Z_5\}$	Forearm Pronation (+) / Supination (-) $\{X_5\}$
-30 to 160 degrees	-40 to 90 degrees	-90 to 40 degrees	0 to 140 degrees	-70 to 70 degrees
Summary of Functional Tasks				
Touch top of head (lift helmet visor), Touch chin (helmet clasp), Arm above head (hammering, twisting wrench, grip hand rail), Arm behind head (adjust backpack), Arm above head (control panel), Arm in front (control panel, throttle control), Arm behind seat (grasp straps or pull release), Arm across chest (grab restraint straps), Mobility (open door)				

Table B-10 Minimum Joint Range of Motion to Perform Functional Tasks of the Lower Body (TBR-006-069)

Hip Flexion (+) / Extension (-) {Z_1}	Hip Abduction (+) / Adduction (-) {Y_1}	Hip External (+) / Internal (-) Rotation {X_1}	Knee Flexion (+) / Extension (-) {Z_2}
0 to 117 degrees	0 to 28 degrees	-5 to 26 degrees	0 to 118 degrees
Summary of Functional Tasks			
Lifting (squatting, bending), Stairs (ascending, descending), Mobility (sitting, kneeling)			

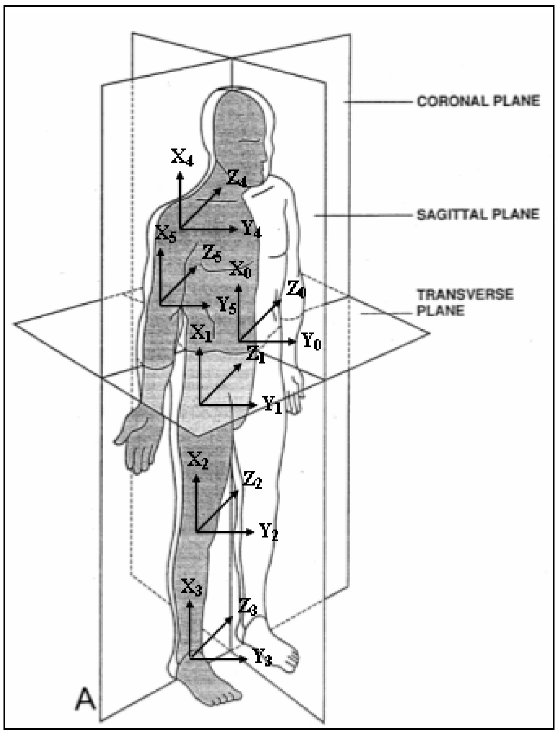


Figure B-1 Planes and axes for measurement of the Joint Angles

B3 Mass Properties

Crewmember whole-body mass, body-segment mass, center of mass location, and moment of inertia data are provided in Tables B-11 through B-16 (only the data in Tables B-11 and B-12 are projected forward to 2015). Two axis systems are used here, anatomical (subscript 'a') and principal (subscript 'p').

The anatomical axis system is based on skeletal landmarks and provides a consistent reference for the principal axes system and the center of volume/mass independent of body segment orientation as described in McConville et al. (1980) and Young et al. (1983). The principal axis of inertia originates at the center of volume/mass.

Regression equations from McConville et al. (1980) and Young et al. (1983) were used to compute the body segment properties (BSP); however, because the sample sizes in these two studies were relatively small (31 and 46 subjects respectively), this document uses data from the ANSUR database for input into the regression equations.

The regression equations from the McConville et al. (1980) and Young et al. (1983) studies were used in their most simple form which uses only the stature and weight of the subject to calculate the volume and moments of inertia. A Matlab code was written to identify all females with a 5th percentile stature (based on the female data only), and all males with a 95th percentile stature (based on the male data only) in the ANSUR database, from this extracted data, the lightest female and heaviest male were identified; these values were then used in the regression equations to compute the BSP. McConville and Young did not generate regression equations to predict all of the BSP presented in this report, below is a description and reasoning (based on the available data) of how each BSP presented here was generated.

For Table B-11 and Table B-12, minimum values correspond to a 1st percentile female in mass, and maximum values correspond to a 99th percentile male in mass. Minimum and maximum values in all other tables correspond to 5th percentile females and 95th percentile males, respectively. These values are considered to be representative of those for a small female and a large male crewmember, respectively.

Whole body mass

Regressions equations from the McConville et al. (1980) and Young et al. (1983) studies were used to compute the whole body volume. Whole body mass was calculated by assuming the density of the human flesh was homogeneous, a density value of 1 g/cm^3 was used. With a value of unity for the density, the mass values are numerically equal to their corresponding volume values.

Whole body center of mass

Assuming that the human flesh was homogeneous, we can also assume that the center of volume is at the center of mass location. McConville et al. (1980) and Young et al. (1983) provided ranges for the location of the center of volume for the male and female, respectively, in each study. Since regression equations were not given for the center of volume, the range values from the McConville et al. (1980) and Young et al. (1983) studies were used here. Specific values for the locations of the center of mass with respect to the anatomical axes were taken from each study to form the range, specifically, the upper range was set by the male upper range, and the lower range was set by the female lower range.

Whole body moments of inertia

Moments of inertia regression equations from the McConville et al. (1980) and Young et al. (1983) studies were used.

Segment mass

Regressions equations from the McConville et al. (1980) and Young et al. (1983) studies were used to compute the segment volume. Segment mass was calculated by assuming the density of the human flesh was homogeneous, a density value of 1 g/cm^3 was used. With a value of unity for the density, the mass values are numerically equal to their corresponding volume values.

Segment center of mass

Assuming that the human flesh was homogeneous, we can also assume that the center of volume is at the center of mass location. McConville et al. (1980) and Young et al. (1983) provided ranges for the location of the center of volume for the male and female, respectively, in each study. Since regression equations were not given for the center of volume, the range values from the McConville et al. (1980) and Young et al. (1983) were used in this update. Specific values for the locations of the center of mass with respect to the anatomical axes were taken from each study to form the range, specifically, the upper range was set by the male upper range, and the lower range was set by the female lower range.

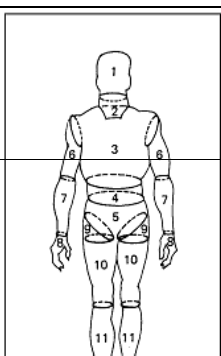
Segment moments of inertia

Regression equations from the McConville et al. (1980) and Young et al. (1983) studies were used to compute the moments of inertia. The moments of inertia presented are those about the principal axes Xp, Yp, and Zp.

Table B-11 Whole-Body Mass of Crewmember (TBR-006-067)

	Crewmember Body Mass (kg, (pounds))	
	Unsuited	**Suited**
Min	42.64 (94)	71.64 (158) (TBR-006-2007)
Max	110.22 (243)	139.26 (307) (TBR-006-2007)

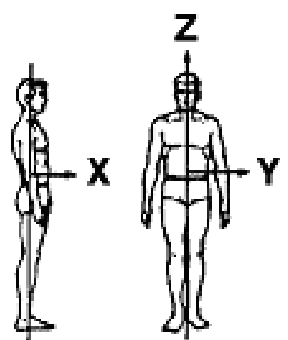
Table B-12 Body Segment Mass Properties for the Male and Female Crewmember (TBR-006-067)



Segment	Mass (kg, (pounds))	
	Min	Max
1 Head	2.99 (6.59)	5.03 (11.08)
2 Neck	0.49 (1.08)	1.39 (3.07)

	3 Thorax	11.35 (25.02)	34.33 (75.69)
	4 Abdomen	2.14 (4.72)	3.25 (7.16)
	5 Pelvis	5.62 (12.4)	16.46 (36.29)
	6 Upper arm	0.91 (2.0)	2.74 (6.04)
	7 Forearm	0.59 (1.29)	1.86 (4.09)
	8 Hand	0.24 (0.52)	0.66 (1.45)
	9 Hip flap	2.22 (4.9)	4.79 (10.55)
	10 Thigh minus hip flap	3.86 (8.12)	8.48 (18.69)
	11 Calf	1.94 (4.28)	5.11 (11.27)
	12 Foot	0.44 (0.98)	1.26 (2.77)
	Torso (5 + 4 + 3)	19.11 (42.13)	54.05 (119.15)
	Thigh (9 + 10)	5.91 (13.03)	13.26 (29.24)
	Forearm plus hand (7+8)	0.82 (1.81)	2.51 (5.54)

Table B-13 Whole Body Center of Mass Location of the Male and Female Crewmember (the axes in the figure below represent the anatomical axes) (TBR-006-067)



Dimension	Min (cm,(in))	Max (cm,(in))
$L(X_a)$	-15.27 (-6.01)	-6.40 (-2.52)
$L(Y_a)$	-1.22 (-0.48)	0.97 (0.38)
$L(Z_a)$	-3.81 (-1.5)	8.15 (3.21)

Table B-14 Body Segment Center of Mass Location of the Crewmember (TBR-006-067)

Segment	Axis	Min (cm,(in))	Max (cm,(in))
Head	X_a	-2.44 (-0.96)	0.53 (0.21)
	Y_a	-0.61 (-0.24)	0.61 (0.24)

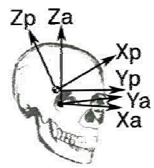
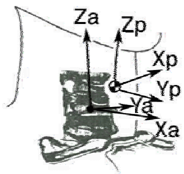
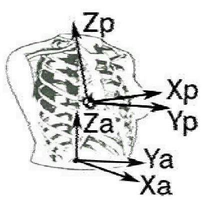
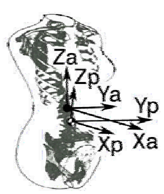
Segment	Axis	Min (cm,(in))	Max (cm,(in))
	Z_a	2.24 (0.88)	4.04 (1.59)
Neck 	X_a	3.40 (1.34)	7.32 (2.88)
	Y_a	-0.56 (-0.22)	0.58 (0.23)
	Z_a	2.92 (1.15)	6.05 (2.38)
Thorax 	X_a	3.76 (1.48)	7.06 (2.78)
	Y_a	-0.81 (-0.32)	0.48 (0.19)
	Z_a	13.44 (5.29)	21.97 (8.65)
Abdomen 	X_a	-1.47 (-0.58)	1.55 (0.61)
	Y_a	-1.65 (-0.65)	2.26 (0.89)
	Z_a	-4.85 (-1.91)	-1.14 (-0.45)

Table B-14 Body Segment Center of Mass Location of the Crewmember (cont.) (TBR-006-067)

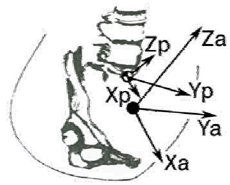
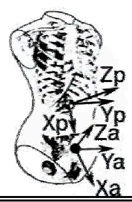
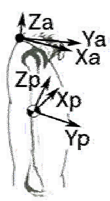
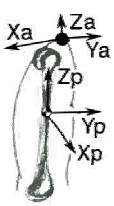
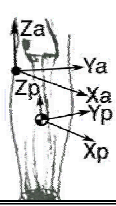
Segment	Axis	Min (cm,(in))	Max (cm,(in))
Pelvis 	X_a	-12.17 (-4.79)	-6.96(-2.74)
	Y_a	-1.32 (-0.52)	0.74 (0.29)
	Z_a	-0.76 (-0.30)	5.18 (2.04)
Torso 	X_a	-10.41 (-4.1)	2.49 (0.98)
	Y_a	-1.52 (-0.60)	1.73 (0.68)
	Z_a	16.33 (6.43)	25.60 (10.08)
Right upper arm 	X_a	-0.71 (-0.28)	-0.91 (-0.36)
	Y_a	1.85 (0.73)	-2.29 (-0.90)
	Z_a	-18.59 (-7.32)	-14.27 (-5.62)
Left upper arm 	X_a	-0.64 (-0.25)	2.59 (1.02)
	Y_a	-3.68 (-1.45)	-1.80 (-0.71)
	Z_a	-18.72 (-7.37)	-14.33 (-5.64)
Right forearm 	X_a	1.02 (0.40)	0.08 (0.03)
	Y_a	-2.11 (-0.83)	4.14 (1.63)
	Z_a	-9.86 (-3.88)	-8.86 (-3.49)

Table B-14 Body Segment Center of Mass Location of the Crewmember (cont.) (TBR-006-067)

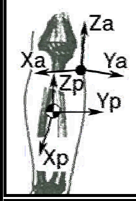
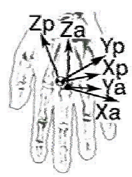
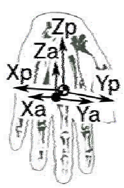
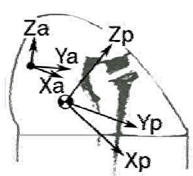
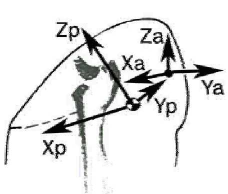
Segment	Axis	Min (cm,(in))	Max (cm,(in))
Left forearm	X_a	1.17 (0.46)	0.13 (0.05)
	Y_a	-0.23 (-0.09)	-2.44 (-0.96)
	Z_a	-9.86 (-3.88)	-9.07 (-3.57)
Right hand	X_a	-0.53 (-0.21)	0.03 (0.01)
	Y_a	0.43 (0.17)	0.13 (0.05)
	Z_a	0.71 (0.28)	1.93 (0.76)
Left hand	X_a	-0.71 (-0.28)	-0.23 (-0.09)
	Y_a	-1.35 (-0.53)	0.89 (0.35)
	Z_a	0.84 (0.33)	2.03 (0.80)
Right hip flap	X_a	-7.77 (-3.06)	1.70 (0.67)
	Y_a	5.66 (2.23)	7.37 (2.90)
	Z_a	-6.73 (-2.65)	-6.05 (-2.38)
Left hip flap	X_a	-8.20 (-3.23)	2.41 (0.95)
	Y_a	-10.67 (-4.2)	-5.18 (-2.04)
	Z_a	-6.96 (-2.74)	-6.20 (-2.44)

Table B-14 Body Segment Center of Mass Location of the Crewmember (cont.) (TBR-006-067)

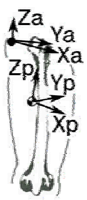
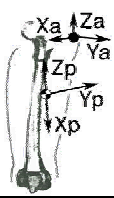
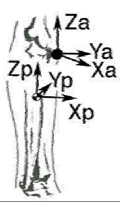
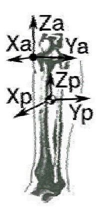
Segment	Axis	Female (cm,(in))	Male (cm,(in))
Right thigh minus flap 	X_a	-3.28 (-1.29)	2.36 (0.93)
	Y_a	5.18 (2.04)	8.38 (3.30)
	Z_a	-24.84 (-9.78)	-23.34 (-9.19)
Left thigh minus flap 	X_a	3.10 (1.22)	2.21 (0.87)
	Y_a	-9.60 (-3.78)	-5.28 (-2.08)
	Z_a	-24.87 (-9.79)	-23.62 (-9.3)
Right calf 	X_a	-4.24 (-1.67)	-0.10 (-0.04)
	Y_a	-6.38 (-2.51)	-4.85(-1.91)
	Z_a	-16.18 (-6.37)	-12.01 (-4.73)
Left calf 	X_a	-4.34 (-1.71)	0.69 (0.27)
	Y_a	4.04 (1.59)	6.83 (2.69)
	Z_a	-16.00 (-6.30)	-12.32 (-4.85)
Right foot 	X_a	-8.51 (-3.35)	-6.63 (-2.61)
	Y_a	-0.28 (-0.11)	0.43 (0.17)
	Z_a	0.46 (0.18)	-0.05 (-0.02)

Table B-14 Body Segment Center of Mass Location of the Crewmember (cont.) (TBR-006-067)

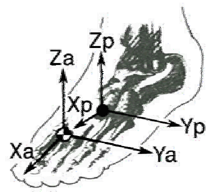
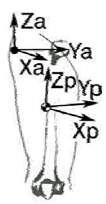
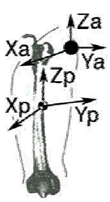
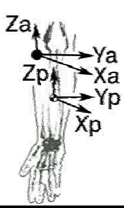
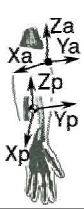
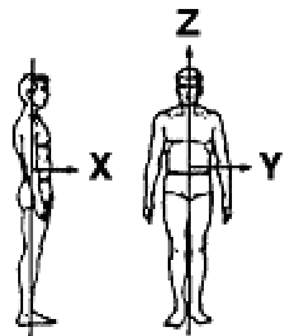
Segment	Axis	Female (cm,(in))	Male (cm,(in))
Left foot 	X_a	-8.71 (-3.43)	-6.48 (-2.55)
	Y_a	-0.86 (-0.34)	0.89 (0.35)
	Z_a	0.33 (0.13)	-0.10 (-0.04)
Right thigh 	X_a	-4.88 (-1.92)	2.11 (0.83)
	Y_a	5.64 (2.22)	8.00 (3.15)
	Z_a	-17.55 (-6.91)	-17.55 (-6.91)
Left thigh 	X_a	-4.75 (-1.87)	2.29 (0.90)
	Y_a	-9.65 (-3.80)	-5.26 (-2.07)
	Z_a	-17.91 (-7.05)	-17.83 (-7.02)
Right forearm plus hand 	X_a	0.43 (0.17)	-0.36 (-0.14)
	Y_a	-2.29 (-0.90)	4.52 (1.78)
	Z_a	-15.54 (-6.12)	-14.99 (-5.9)
Left forearm plus hand 	X_a	0.43 (0.17)	0
	Y_a	0.79 (0.31)	-2.82 (-1.11)
	Z_a	-15.37 (-6.05)	15.01 (-5.91)

Table B-15 Whole Body Moment of Inertia of the Crewmember (the axes in the figure below represent the principal axes) (TBR-006-067)



Axis	Min ($kg \cdot m^2$ ($lb \cdot ft^2$))	Max ($kg \cdot m^2$ ($lb \cdot ft^2$))
X_p	6.59 (156.38)	17.69 (419.79)
Y_p	6.12 (145.23)	16.43 (389.89)
Z_p	0.73 (17.32)	2.05 (48.65)

Table B-16 Body Segment Moment of Inertia of the Crewmember (the axes in the figure below represent the principal axes) (TBR-006-067)

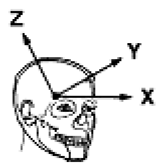
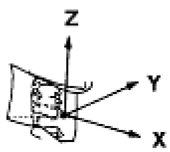
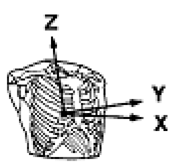
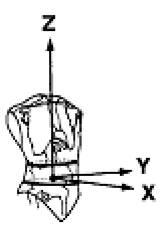
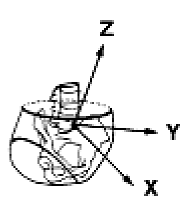
<table>
<tr><th>Segment</th><th>Axis</th><th>Min (kg·m^{2}x10^{-3} (lb·ft^{2}x10^{-3}))</th><th>Max (kg·m^2 x10^{-3} (lb·ft^{2}x10^{-3})</th></tr>
<tr><td rowspan="3">Head

</td><td>X_p</td><td>15 (351)</td><td>22 (512)</td></tr>
<tr><td>Y_p</td><td>18 (424)</td><td>25 (587)</td></tr>
<tr><td>Z_p</td><td>14 (322)</td><td>16 (379)</td></tr>
<tr><td rowspan="3">Neck

</td><td>X_p</td><td>1 (17)</td><td>2 (53)</td></tr>
<tr><td>Y_p</td><td>1 (23)</td><td>3 (64)</td></tr>
<tr><td>Z_p</td><td>1 (25)</td><td>3 (81)</td></tr>
<tr><td rowspan="3">Thorax

</td><td>X_p</td><td>183 (4346)</td><td>680 (16134)</td></tr>
<tr><td>Y_p</td><td>135 (3206)</td><td>505 (11984)</td></tr>
<tr><td>Z_p</td><td>119 (2833)</td><td>431 (10236)</td></tr>
<tr><td rowspan="3">Abdomen

</td><td>X_p</td><td>15 (347)</td><td>23 (540)</td></tr>
<tr><td>Y_p</td><td>10 (241)</td><td>13 (309)</td></tr>
<tr><td>Z_p</td><td>21 (500)</td><td>35 (826)</td></tr>
<tr><td rowspan="3">Pelvis

</td><td>X_p</td><td>46 (1092)</td><td>148 (3514)</td></tr>
<tr><td>Y_p</td><td>34 (810)</td><td>137 (3258)</td></tr>
<tr><td>Z_p</td><td>61 (1440)</td><td>173 (4104)</td></tr>
</table>

Table B-16 Body Segment Moment of Inertia of the Crewmember (cont.) (TBR-006-067)

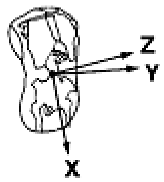
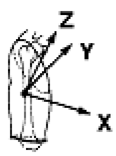
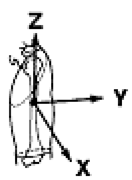
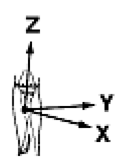
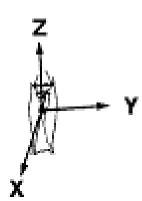
Segment	Axis	Min ($kg{\cdot}m^2 x10^{-3}$ ($lb{\cdot}ft^2 x10^{-3}$))	Max ($kg{\cdot}m^2 x10^{-3}$ ($lb{\cdot}ft^2 x10^{-3}$))
Torso 	X_p	638 (15143)	2030 (48178)
	Y_p	577 (13702)	1840 (43654)
	Z_p	205 (4865)	644 (15273)
Right upper arm 	X_p	5 (129)	18 (430)
	Y_p	6 (133)	19 (462)
	Z_p	1 (24)	4 (92)
Left upper arm 	X_p	5 (126)	18 (420)
	Y_p	5 (130)	19 (449)
	Z_p	1 (22)	4 (89)
Right forearm 	X_p	3 (67)	12 (276)
	Y_p	3 (65)	12 (282)
	Z_p	0 (11)	2 (43)
Left forearm 	X_p	3 (66)	11 (257)
	Y_p	3 (63)	11 (265)
	Z_p	0 (11)	2 (39)

Table B-16 Body Segment Moment of Inertia of the Crewmember (cont.) (TBR-006-067)

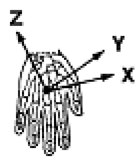
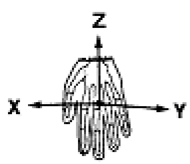
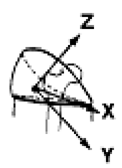
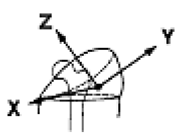
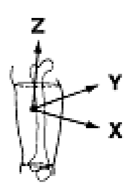
Segment	Axis	Min (kg·m^{2}x10^{-3} (lb·ft^{2}x10^{-3}))	Max (kg·m^{2}x10^{-3} (lb·ft^{2}x10^{-3}))
Right hand 	X_p	1 (14)	2 (38)
	Y_p	0 (11)	1 (31)
	Z_p	0 (4)	1 (13)
Left hand 	X_p	1 (15)	2 (37)
	Y_p	1 (13)	1 (31)
	Z_p	0 (4)	1 (12)
Right hip flap 	X_p	8 (191)	17 (412)
	Y_p	10 (246)	22 (530)
	Z_p	13 (318)	29 (696)
Left hip flap 	X_p	8 (188)	17 (398)
	Y_p	11 (255)	22 (519)
	Z_p	14 (324)	28 (671)
Right thigh minus flap 	X_p	34 (800)	79 (1885)
	Y_p	33 (785)	82 (1941)
	Z_p	14 (327)	32 (753)

Table B-16 Body Segment Moment of Inertia of the Crewmember (cont.) (TBR-006-067)

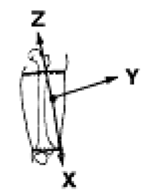
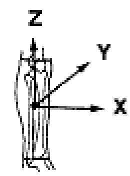
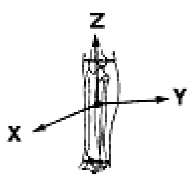
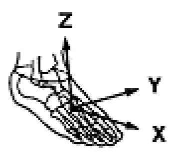
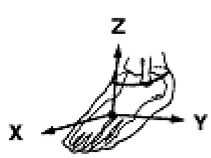
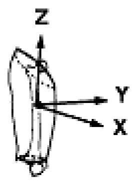
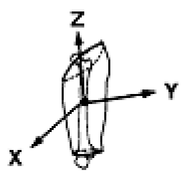
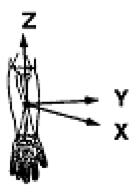
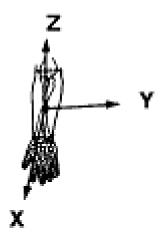
Segment	**Axis**	**Min (kg·m^{2}x10^{-3} (lb·ft^{2}x10^{-3}))**	**Max (kg·m^{2}x10^{-3} (lb·ft^{2}x10^{-3}))**
Left thigh minus flap 	X_p	34 (798)	75 (1784)
	Y_p	33 (789)	79 (1878)
	Z_p	13 (317)	31 (729)
Right calf 	X_p	26 (615)	75 (1790)
	Y_p	26 (613)	76 (1815)
	Z_p	3 (73)	9 (210)
Left calf 	X_p	26 (614)	77 (1826)
	Y_p	26 (615)	78 (1855)
	Z_p	3 (70)	9 (215)
Right foot 	X_p	0 (9)	1 (24)
	Y_p	2 (37)	5 (130)
	Z_p	2 (39)	6 (138)
Left foot 	X_p	0 (9)	1 (24)
	Y_p	2 (39)	5 (127)
	Z_p	2 (41)	6 (134)

Table B-16 Body Segment Moment of Inertia of the Crewmember (cont.) (TBR-006-067)

Segment	Axis	Min (kg·m^{2}x10^{-3} (lb·ft^{2}x10^{-3}))	Max (kg·m^{2}x10^{-3} (lb·ft^{2}x10^{-3}))
Right thigh 	X_p	85 (2009)	208 (4940)
	Y_p	87 (2063)	220 (5215)
	Z_p	27 (651)	59 (1401)
Left thigh 	X_p	85 (2022)	200 (4757)
	Y_p	88 (2088)	212 (5024)
	Z_p	27 (649(	57 (1350)
Right forearm plus hand 	X_p	11 (262)	40 (939)
	Y_p	11 (257)	39 (935)
	Z_p	1 (16)	2 (58)
Left forearm plus hand 	X_p	11 (260)	37 (887)
	Y_p	11 (256)	37 (881)
	Z_p	1 (15)	2 (53)

B4 Strength

The information in the "other operations" and "Maximum Crew Operation Loads" columns were derived from a collection of journal articles associated with human strength data. In addition, other references were used such as the MILSTD1472 and the Occupational and Biomechanics textbook (Chaffin, D. B., Occupation Biomechanics, Second Edition, John Wiley & Sons, Inc., 1991).were used to set a standard for very specific strength data such as lifting strength. Since there are so many variations in which strength data can be collected, the data in this table was consolidated in order to group similar motions and actions under the same category. The values in the criticality 1 and 2 columns were derived by applying a factor of safety of 2 and 1.5 respectively.

Criticality 1 and criticality 2 values were obtained by dividing the value in the other operations column by a factor of safety of 2 and 1.5 respectively. The values in the criticality 1 and 2 columns also include the decrement factor(s) to reflect the de-conditioning effects on crewmembers after an extended duration of mission. Criticality 1 load limits should be used for crew safety situations and the design of items where a single failure could result in loss of life or vehicle. Criticality 2 load limits should be used for the design of items where a single failure could result in a loss of mission.

Table B-17A – Unsuited Strength Data

Type of Strength	Minimum Crew Operation Loads (N(lbf))			Maximum Crew Operational Loads (N(lbf))
	Crit 1 Operations	Crit 2 Operations	Other Operations	
One Handed Pulls				
Seated Horizontal Pull In[2]	111 (25)	147 (33)	276 (62)	449 (101)
Seated Vertical Pull Down[2]	125 (28)	165 (37)	311 (70)	587 (132)
Seated Vertical Pull Up[2]	49 (11)	67 (15)	125 (28)	756 (170)
Standing Vertical Pull Up[2]	53 (12)	71 (16)	133 (30)	725 (163)
Two Handed Pulls				
Standing Vertical Pull Down [2]	138 (31)	182 (41)	343 (77)	707 (159)
Standing Pull in[2]	58 (13)	80 (18)	147 (33)	391 (88)
Standing Vertical Pull Up[2]	89 (20)	116 (26)	218 (49)	1437 (323)
Seated Vertical Pull Up[2]	93 (21)	125 (28)	236 (53)	1188 (267)
One Handed Push				
Seated Horizontal Push Out[2]	89 (20)	116 (26)	218 (49)	436 (98)
Seated Vertical Push Up[2]	67 (15)	85 (19)	160 (36)	280 (63)
Two Handed Push				
Standing Vertical Push Down[2]	102 (23)	133 (30)	254 (57)	525 (118)
Standing Horizontal Push Out[1]	62 (14)	85 (19)	165 (37)	596 (134)
Standing Vertical Push Up[2]	76 (17)	98 (22)	187 (42)	1094 (246)
Arm				
Arm Pull[2]	44 (10)	58 (13)	107 (24)	249 (56)
Arm Push[2]	40 (9)	53 (12)	98 (22)	222 (50)

Arm Up[2]	18 (4)	22 (5)	40 (9)	107 (24)
Arm Down[2]	22 (5)	31 (7)	58 (13)	116 (26)
Arm In[2]	22 (5)	31 (7)	58 (13)	98 (22)
Arm Out[2]	13 (3)	18 (4)	36 (8)	76 (17)
LIFTING				
Lifting Strength[2]	36 (8)	49 (11)	93 (21)	1228 (276)
ELBOW				
Flexion[2]	13 (3)	18 (4)	36 (8)	347 (78)
Extension[2]	27 (6)	36 (8)	67 (15)	249 (56)
Pronation[2]	165 (37)	222 (50)	414 (93)	876 (197)
Supination[2]	160 (36)	214 (48)	405 (91)	761 (171)
WRIST & HAND				
Wrist Flexion[2]	31 (7)	40 (9)	76 (17)	209 (47)
Wrist Extension[2]	13 (3)	18 (4)	36 (8)	85 (19)
Pinch [1]	9 (2)	13 (3)	18 (4)	200 (45)
Grasp[1]	347 (78)	463 (104)	694 (156)	1219 (274)
Grip[1]	49 (11)	67 (15)	102 (23)	783 (176)
LEG				
Hip Flexion[2]	116 (26)	156 (35)	289 (65)	645 (145)
Hip Extension[2]	191 (43)	254 (57)	476 (107)	658 (148)
Leg Press[1]	618 (139)	827 (186)	1552 (349)	2584 (581)
Knee Flexion[1]	53 (12)	71 (16)	138 (31)	325 (73)
Knee Extension[1]	142 (32)	191 (43)	383 (86)	783 (176)

[1]Post space flight maximal measured strength decrement.

[2]Post space flight estimated strength decrement. Range is 0%-26%. Average estimated is 20%. Based on max EDOMP Data. Not all motions were measured on EDOMP.

Table B-17B – Pressurized-Suited Strength Data

TYPE OF STRENGTH	DESIGN LIMITS N (lbf)			STRUCTURAL LIMIT
	CRIT 1 OPERATIONS	CRIT 2 OPERATIONS	OTHER OPERATIONS	
ONE HANDED PULLS				
Seated Horizontal Pull In[2]	70 (16)	93 (21)	139 (31)	224 (50)
Seated Vertical Pull Down[2]	78 (18)	104 (23)	156 (35)	295 (66)
Seated Vertical Pull Up[2]	32 (7)	42 (9)	63 (14)	379 (85)
Standing Vertical Pull Up[2]	33 (7)	44 (10)	66 (15)	362 (81)
TWO HANDED PULLS				
Standing Vertical Pull Down [2]	86 (19)	114 (26)	171 (38)	354 (80)
Standing Pull in[2]	37 (8)	49 (11)	74 (17)	196 (44)
Standing Vertical	55 (12)	73 (16)	109 (25)	719 (162)

Pull Up[2]				
Seated Vertical Pull Up[2]	60 (13)	79 (18)	119 (27)	595 (134)
One Handed Push				
Seated Horizontal Push Out[2]	55 (12)	73 (16)	109 (25)	218 (49)
Seated Vertical Push Up[2]	41(9)	54 (12)	81 (18)	141 (32)
Two Handed Push				
Standing Vertical Push Down[2]	64 (14)	85 (19)	127 (29)	263 (59)
Standing Horizontal Push Out[1]	42 (9)	55 (12)	83 (19)	298 (67)
Standing Vertical Push Up[2]	47 (11)	63 (14)	94 (21)	547 (123)
Arm				
Arm Pull[2]	27 (6)	36 (8)	54 (12)	125 (28)
Arm Push[2]	25 (6)	33 (7)	49 (11)	111 (25)
Arm Up[2]	10 (2)	14 (3)	20 (4)	54 (12)
Arm Down[2]	15 (3)	20 (4)	29 (7)	58 (13)
Arm In[2]	15 (3)	20 (4)	29 (7)	49 (11)
Arm Out[2]	9 (2)	12 (3)	18 (4)	38 (9)
Lifting				
Lifting Strength[2]	-	-	-	-
Elbow				
Flexion[2]	10 (2)	12 (3)	19 (4)	183 (41)
Extension[2]	22 (5)	29 (7)	44 (10)	161 (36)
Pronation[2]	-	-	-	-
Supination[2]	-	-	-	-
Wrist & Hand				
Wrist Flexion[2]	19 (4)	25 (6)	37 (8)	101 (23)
Wrist Extension[2]	7 (2)	9 (2)	14 (3)	33 (7)
Pinch [1]	-	-	-	-
Grasp[1]	-	-	-	-
Grip[1]	-	-	-	-
Leg				
Hip Flexion[2]	-	-	-	-
Hip Extension[2]	-	-	-	-
Leg Press[1]	-	-	-	-
Knee Flexion[1]	-	-	-	-
Knee Extension[1]	-	-	-	-

[1]Post space flight maximal measured strength decrement for minimum crew operational loads only.

[2]Post space flight estimated strength decrement for minimum crew operational loads only. Range is 0%-26%. Average estimated is 20%. Based on max EDOMP Data. Not all motions were measured on EDOMP.

Pre-post data derived from EDOMP DSO 477 (N=5, non-exercisers, percent loss derived from Mean + standard error of the mean), as follows:

Knee Flexion: - 23%, concentric strength, 30 degrees/second

Knee Extension: - 26%, concentric strength, 30 degrees/second

Appendix C – Natural and Induced Environments

C1 Atmosphere

Table C-1 – Criteria for Assignment of Toxicological Hazard Levels

Hazard level	Irritancy	Systemic Effects	Containability and Decontamination
0 (Non hazard)	Slight irritation that lasts <30 minutes and will not require therapy.	None	Gas, solid, or liquid may or may not be containable.
1 (Critical)	Slight to moderate irritation that lasts >30 min and will require therapy.	Minimal effects, no potential for lasting internal tissue damage.	Gas, solid, or liquid may or may not be containable. However, the crew will be protected from liquids and solids by surgical masks, gloves, and goggles.
2 (Catastrophic)	Moderate to severe irritation that has the potential for long-term performance decrement and will require therapy. Eye Hazards: May cause permanent damage.	None	Either a solid or nonvolatile liquid. Can be contained by a cleanup procedure and disposed of. The crew will be protected by 5-micron surgical masks, gloves, and goggles.
3 (Catastrophic)	Irritancy alone does not constitute a level 3 hazard.	Appreciable effects on coordination, perception, memory, etc., or has the potential for long-term (delayed) serious injury (e.g., cancer), or may result in internal tissue damage.	Either a solid or nonvolatile liquid that can be contained by a cleanup crew and disposed of. Surgical masks and gloves will not protect the crew. Either quick-don masks or SEBS and gloves are required.
4 (Catastrophic)	Moderate to severe irritancy that has the potential for long-term crew performance decrement (for eye-only hazards, there may be a risk of permanent eye damage.) Note: Will require therapy if crew is exposed.	Appreciable effects on coordination, perception, memory, etc., or the potential for long-term (delayed) serious injury (e.g., cancer) or may result in internal tissue damage.	Gas, volatile liquid, or fumes that are not containable. The ARS will be used to decontaminate. Either the quick-don masks or the SEBs are required or the contaminated module will be evacuated.

C2 Acceleration

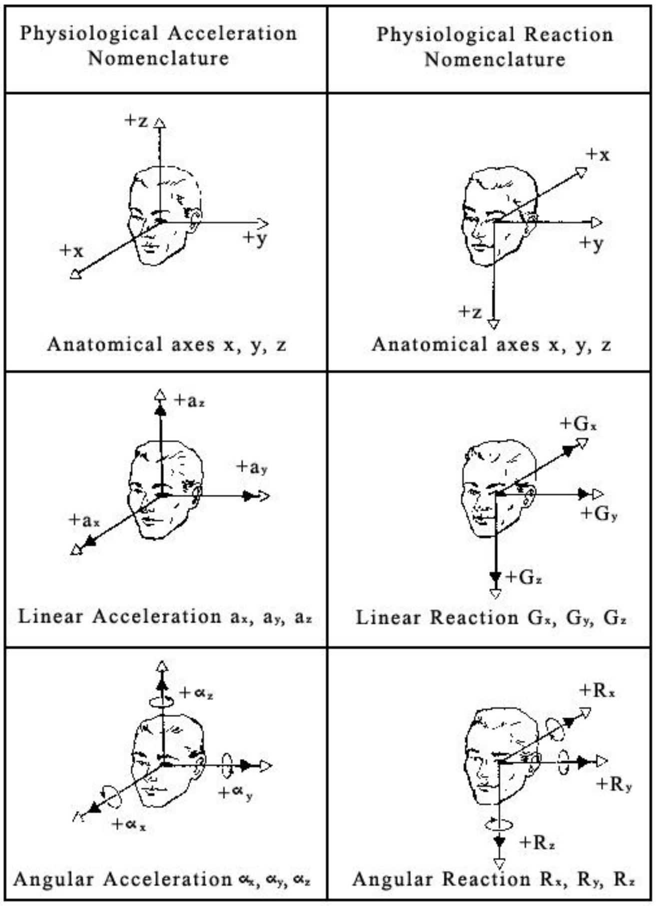


Figure C-2 – Acceleration Environment Coordinate System

Table C-2 – Direction and Inertial Resultant of Body Acceleration

a. Direction of Acceleration

Linear Motion	Aircraft Standard	Acceleration Description
Forward	$+a_x$	Forward acceleration
Backward	$-a_x$	Backward acceleration
Upward	$+a_z$	Headward acceleration
Downward	$-a_z$	Footward acceleration
To the Right	$-a_y$	Rightward acceleration
To the Left	$+a_y$	Leftward acceleration

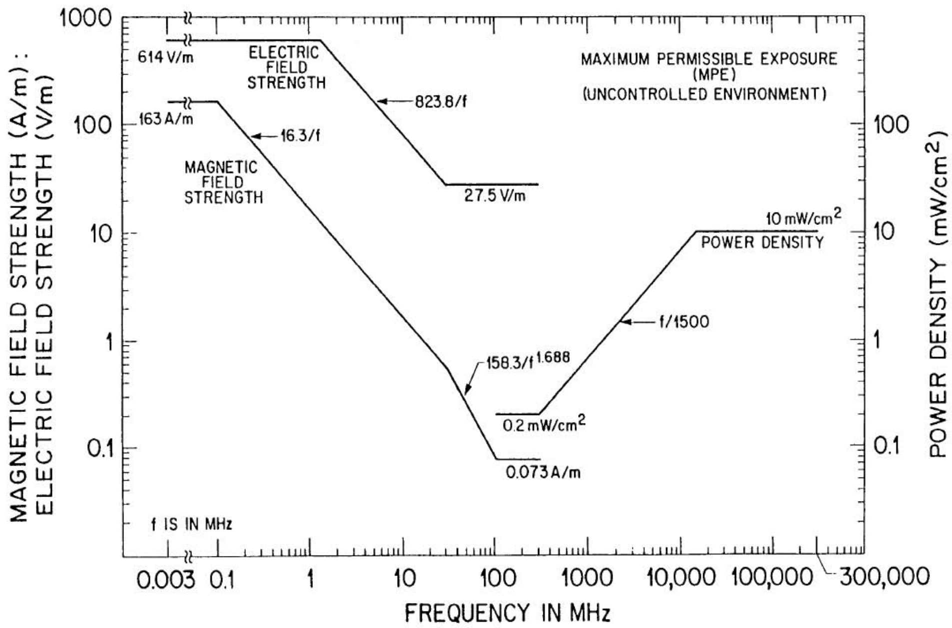
b. Inertial Resultant of Body Acceleration

Linear Motion	Physiologic Descriptive	Physiologic Standard	Vernacular Descriptive
Forward	Transverse anterior-posterior G, prone G, chest to back G	+Gx	Eyeballs-in
Backward	Transverse posterior-anterior G, supine G, back to chest G	-Gx	Eyeballs-out
Upward	Positive G	+Gz	Eyeballs-down
Downward	Negative G	-Gz	Eyeballs-up
To the right	Lateral G	+Gy	Eyeballs-left
To the left	Lateral G	-Gy	Eyeballs-right

Footnotes:

Large letter, G, used as unit to express inertial resultant to whole body acceleration in multiples of the magnitude of the acceleration of gravity. Acceleration of gravity, g = 9.80665 m/s^2

C3 Non-Ionizing Radiation



Graphic Representation of Maximum Permissible Exposure in Terms of Field and Power Density

Figure C-3 – Radio-Frequency Occupational Exposure Limits (Illustrated to Show Whole Body Resonance Effects Around 100 MHz)

Table C-3 – Occupational Exposure Limits for Radio Frequency Electromagnetic Fields

1 Frequency Range (MHz)	2 Electric Field Strength (E) (V/m)	3 Magnetic Field Strength (H) (A/m)	4 Power Density (S) E–Field, H–Field (mW/cm^2)	5 Averaging Time (minutes)	
				$\|E\|^2$, S or	$\|H\|^2$
0.003 – 0.1	614	163	(100, 1 000 000)#	6	6
0.1 – 1.34	614	$16.3/f$	(100, 10 000/f^2)#	6	6
1.34 – 3.0	$823.8/f$	$16.3/f$	(180/f^2, 10 000/f^2)	$f^2/0.3$	6
3.0 – 30	$823.8/f$	$16.3/f$	(180/f^2, 10 000/f^2)	30	6
30 – 100	27.5	$158.3/f^{1.668}$	(0.2, 940 000/$f^{3.336}$)	30	$0.0636f^{1.337}$
100 – 300	27.5	0.0729	0.2	30	30
300 – 3 000	-	-	$f/1500$	30	
3 000 – 15 000	-	-	$f/1500$	90 000/f	
15 000 – 300 000			10	616 000/$f^{1.2}$	

Note:

(1) + The exposure values in terms of electric field and magnetic field strengths are the values obtained by spatially averaging the square of the fields over an area equivalent to the vertical cross–sectional area of the human body (projected area).

(2) # These plane–wave equivalent power density values, although not appropriate for near–field conditions, are commonly used as a convenient comparison with Maximum Permissible Exposures (MPEs) at higher frequencies and are displayed on some instruments in use.

Table C-4 – Point Source Laser Ocular Exposure Limits

Wavelength, λ (μm)	Exposure Duration, t (s)	Maximum Permissible Exposure (MPE)	Notes for Calculation and Measurement
Ultraviolet			
0.200 to 0.302	10^{-9} to 3×10^{4}	3×10^{-3} J • cm^{-2}	
0.303	10^{-9} to 3×10^{4}	4×10^{-3} J • cm^{-2}	
0.304	10^{-9} to 3×10^{4}	6×10^{-3} J • cm^{-2}	or $0.56t^{1/4}$ J • cm^{-2},
0.305	10^{-9} to 3×10^{4}	1.0×10^{-2} J • cm^{-2}	
0.306	10^{-9} to 3×10^{4}	1.6×10^{-2} J • cm^{-2}	whichever is lower
0.307	10^{-9} to 3×10^{4}	2.5×10^{-2} J • cm^{-2}	
0.308	10^{-9} to 3×10^{4}	4.0×10^{-2} J • cm^{-2}	
0.309	10^{-9} to 3×10^{4}	6.3×10^{-2} J • cm^{-2}	1 mm limiting aperture
0.310	10^{-9} to 3×10^{4}	1.0×10^{-1} J • cm^{-2}	
0.311	10^{-9} to 3×10^{4}	1.6×10^{-1} J • cm^{-2}	
0.312	10^{-9} to 3×10^{4}	2.5×10^{-1} J • cm^{-2}	
0.313	10^{-9} to 3×10^{4}	4.0×10^{-1} J • cm^{-2}	
0.314	10^{-9} to 3×10^{4}	6.3×10^{-1} J • cm^{-2}	
0.315 to 0.400	10^{-9} to 10	$0.56\, t^{1/4}$ J • cm^{-2}	
0.315 to 0.400	10 to 3×10^{4}	1 J • cm^{-2}	
0.315 to 0.400	10^{3} to 3×10^{4}	1×10^{-3} J • cm^{-2}	
Visible & Near Infrared			
0.400 to 0.700	10^{-9} to 1.8×10^{-5}	5×10^{-7} J • cm^{-2}	
0.400 to 0.700	1.8×10^{-5} to 10	$1.8\, t^{3/4} \times 10^{-3}$ J • cm^{-2}	
0.400 to 0.550	10 to 10^{4}	10×10^{-3} J • cm^{-2}	
0.550 to 0.700	10 to T_1	$1.8\, t^{3/4} \times 10^{-3}$ J • cm^{-2}	
0.550 to 0.700	T_1 to 10^{4}	$10\, C_B \times 10^{-3}$ J • cm^{-2}	
0.400 to 0.700	10^{4} to 3×10^{4}	$C_B \times 10^{-6}$ W • cm^{-2}	7 mm limiting aperture
0.700 to 1.050	10^{-9} to 1.8×10^{-5}	$5\, C_A \times 10^{-7}$ J • cm^{-2}	
0.700 to 1.050	1.8×10^{-5} to 10^{3}	$1.8\, C_A t^{3/4} \times 10^{-3}$ J • cm^{-2}	
1.051 to 1.400	10^{-9} to 5×10^{-5}	5×10^{-6} J • cm^{-2}	
1.051 to 1.400	5×10^{-5} to 10^{3}	$9\, t^{3/4} \times 10^{-3}$ J • cm^{-2}	
0.700 to 1.400	10^{3} to 3×10^{4}	$320\, C_A \times 10^{-6}$ W • cm^{-2}	
Far Infrared			
1.4 to 10^{3}	10^{-9} to 10^{-7}	10^{-2} J • cm^{-2}	
	10^{-7} to 10	$0.56\, t^{1/4}$ J • cm^{-2}	
	>10	0.1 W • cm^{-2}	
1.54 only	10^{-9} to 10^{-6}	1.0 J • cm^{-2}	

Notes: $C_A = 1$ for $\lambda = 0.400$ to 0.700 μm,
$C_A = 10^{2.0(\lambda - 0.700)}$ for $\lambda = 0.700$ to 1.050 μm
$C_A = 5$ for $\lambda = 1.050$ to 1.400 μm
$C_B = 1$ for $\lambda = 0.400$ to 0.550 μm
$C_B = 10^{15(\lambda - 0.550)}$ for $\lambda = 0.550$ to 0.700 μm
$T_1 = 10 \times 10^{20(\lambda - 0.550)}$ for $\lambda = 0.550$ to 0.700 μm

Table C-5 – Extended Source Laser Eye Exposure Limits

Wavelength, λ (μm)	Exposure Duration, t (s)	Maximum Permissible Exposure (MPE)	
Ultraviolet			
0.200 to 0.302	10^{-9} to 3×10^{4}	3×10^{-3} J • cm^{-2}	or $0.56\, t^{1/4}$ J • cm^{-2}, whichever is lower; 1 mm limiting aperture
0.303	10^{-9} to 3×10^{4}	4×10^{-3} J • cm^{-2}	
0.304	10^{-9} to 3×10^{4}	6×10^{-3} J • cm^{-2}	
0.305	10^{-9} to 3×10^{4}	1.0×10^{-2} J • cm^{-2}	
0.306	10^{-9} to 3×10^{4}	1.6×10^{-2} J • cm^{-2}	
0.307	10^{-9} to 3×10^{4}	2.5×10^{-2} J • cm^{-2}	
0.308	10^{-9} to 3×10^{4}	4.0×10^{-2} J • cm^{-2}	
0.309	10^{-9} to 3×10^{4}	6.3×10^{-2} J • cm^{-2}	
0.310	10^{-9} to 3×10^{4}	1.0×10^{-1} J • cm^{-2}	
0.311	10^{-9} to 3×10^{4}	1.6×10^{-1} J • cm^{-2}	
0.312	10^{-9} to 3×10^{4}	2.5×10^{-1} J • cm^{-2}	
0.313	10^{-9} to 3×10^{4}	4.0×10^{-1} J • cm^{-2}	
0.314	10^{-9} to 3×10^{4}	6.3×10^{-1} J • cm^{-2}	
0.315 to 0.400	10^{-9} to 10	$0.56\, t^{1/4}$ J • cm^{-2}	
0.315 to 0.400	10 to 3×10^{4}	1 J • cm^{-2}	
Visible	10^{-9} to 10	$10\, t^{1/3}$ J • cm^{-2} • sr^{-1}	1 mm limiting aperture or α_{min}, whichever is greater
0.400 to 0.700	10 to 10^{4}	21 J • cm^{-2} • sr^{-1}	
0.400 to 0.550	10 to T_1	$3.83\, t^{3/4}$ J • cm^{-2} • sr^{-1}	
0.550 to 0.700	T_1 to 10^{4}	$21\, C_B$ J • cm^{-2} • sr^{-1}	
0.550 to 0.700	10^{3} to 3×10^{4}	$2.1\, C_B \times 10^{-3}$ W • cm^{-2} • sr^{-1}	
0.400 to 0.700			
Near Infrared	10^{-9} to 10	$10\, C_A\, t^{1/3}$ J • cm^{-2} • sr^{-1}	
0.700 to 1.400	10 to 10^{3}	$3.83\, C_A\, t^{3/4}$ J • cm^{-2} • sr^{-1}	
0.700 to 1.400	10^{-3} to 3×10^{4}	$0.64\, C_A$ W • cm^{-2} • sr^{-1}	
1.051 to 1.400			
Far Infrared	10^{-9} to 10^{-7}	10^{-2} J • cm^{-2}	
1.4–10^{3}	10^{-7} to 10	$0.56\, t^{1/4}$ J • cm^{-2}	
	>10	0.1 W • cm^{-2}	
1.54 Only	10^{-9} to 10^{-6}	1.0 J • cm^{-2}	

Notes: $C_A = 1$ for $\lambda = 0.400$ to 0.700 μm,
$C_A = 10^{2.0(\lambda - 0.700)}$ for $\lambda = 0.700$ to 1.050 μm
$C_A = 5$ for $\lambda = 1.051$ to 1.400 μm
$C_B = 1$ for $\lambda = 0.400$ to 0.550 μm
$C_B = 10^{15(\lambda - 0.550)}$ for $\lambda = 0.550$ to 0.700 μm
$T_1 = 10 \times 10^{20(\lambda - 0.550)}$ for $\lambda = 0.550$ to 0.700 μm

Table C-6 – Maximum Permissible Exposure (MPE) for Skin Exposure to a Laser Beam

Wavelength, λ (μm)	Exposure Duration, t (s)	Maximum Permissible Exposure (MPE)	Notes for Calculation and Measurement
Ultraviolet			
0.200 to 0.302	10^{-9} to 3 x 10^{4}	3 x 10^{-3} J • cm^{-2}	$0.56\ t^{1/4}$ J • cm^{-2}, whichever is lower
0.303	10^{-9} to 3 x 10^{4}	4 x 10^{-3} J • cm^{-2}	
0.304	10^{-9} to 3 x 10^{4}	6 x 10^{-3} J • cm^{-2}	
0.305	10^{-9} to 3 x 10^{4}	1.0 x 10^{-2} J • cm^{-2}	
0.306	10^{-9} to 3 x 10^{4}	1.6 x 10^{-2} J • cm^{-2}	
0.307	10^{-9} to 3 x 10^{4}	2.5 x 10^{-2} J • cm^{-2}	
0.308	10^{-9} to 3 x 10^{4}	4.0 x 10^{-2} J • cm^{-2}	
0.309	10^{-9} to 3 x 10^{4}	6.3 x 10^{-2} J • cm^{-2}	1 mm limiting aperture
0.310	10^{-9} to 3 x 10^{4}	1.0 x 10^{-1} J • cm^{-2}	
0.311	10^{-9} to 3 x 10^{4}	1.6 x 10^{-1} J • cm^{-2}	
0.312	10^{-9} to 3 x 10^{4}	2.5 x 10^{-1} J • cm^{-2}	
0.313	10^{-9} to 3 x 10^{4}	4.0 x 10^{-1} J • cm^{-2}	
0.314	10^{-9} to 3 x 10^{4}	6.3 x 10^{-1} J • cm^{-2}	
0.315 to 0.400	10^{-9} to 10	$0.56\ t^{1/4}$ J • cm^{-2}	
0.315 to 0.400	10 to 10^{3}	1 J • cm^{-2}	
0.315 to 0.400	10^{3} to 3 x 10^{4}	1 x10^{-3} J • cm^{-2}	
Visible & Near Infrared			
0.400 to 1.400	10^{-9} to 10^{-7}	$2\ C_A$ x 10^{-2} J • cm^{-2}	1 mm limiting aperture
	10^{-7} to 10	$1.1\ C_A\ t^{1/4}$ J • cm^{-2}	
	10 to 3 x 10^{4}	$0.2\ C_A$ W • cm^{-2}	
Far Infrared			
1.4 to 10^{3}	10^{-9} to 10^{-7}	10^{-2} J • cm^{-21}	1 mm limiting aperture for 1.4 to 100 μm
	10^{-7} to 10	$0.56\ t^{1/4}$ J • cm^{-2}	
	>10	0.1 W • cm^{-2}	11 mm limiting aperture for 0.1 to 1 mm
1.54 Only	10^{-9} to 10^{-6}	1.0 J • cm^{-2}	

Table C-7 – Intrabeam MPE for the Eye and Skin for Selected CW Lasers

Laser Type	Primary Wavelength (nm)	Maximum Permissible Exposure (MPE) Eye	Skin
Helium–Cadmium Argon	441.6 488/514.5	a) 2.5 mW • cm^{-2} for 0.25 s b) 10 mJ • cm^{-2} for 10 to 104 s c) 1 μW • cm^{-2} for t > 104 s	0.2 W • cm^{-2} for t >10s
Helium–Neon	632.8	a) 2.5 mW • cm^{-2} for 0.25 s b) 10 mJ • cm^{-2} for 10 s c) 170 mJ • cm^{-2} for t > 453 s d) 17 μW • cm^{-2} for t > 104 s	0.2 W • cm^{-2} for t >10s
Krypton	647	a) 2.5 mW • cm^{-2} for 0.25 s b) 10 mJ • cm^{-2} for 10 s c) 280 mJ • cm^{-2} for t > 871 s d) 28 μW • cm^{-2} for t > 104 s	0.2 W • cm^{-2} for t >10s

Laser Type	Primary Wavelength (nm)	Maximum Permissible Exposure (MPE) Eye	Skin
Neodymium: YAG	1,064	1.6 m W • cm^{-2} for t >1000 s	1.0 W • cm^{-2}
Gallium–Arsenide at room temp	905	0.8 m W • cm^{-2} for t >1000 s	0.5 W • cm^{-2} for t > 10s
Helium–Cadmium	325	1 J • cm–2 for 10 to 3 x 10^{4}s	a) 1 J • cm^{-2} for 10 to 1000s b) 1 mW • cm^{-2} for t > 1000s
Nitrogen	337.1		
Carbon–dioxide (and other lasers 1.4 µm to 1000 µm)	10,600	0.1 W • cm^{-2} for t > 10 s	0.1 W • cm^{-2} for t > 10 s

Table C-8 – Blue-Light and Retinal Thermal Hazard Functions

Wavelength (nm)	Blue-Light Hazard Function, B(λ)	Retinal Thermal Hazard Function, R(λ)
305-335	0.01	-
340	0.01	-
345	0.01	-
350	0.01	-
355	0.01	-
360	0.01	-
365	0.01	-
370	0.01	-
375	0.01	-
380	0.01	0.01
385	0.0125	0.0125
390	0.025	0.025
395	0.050	0.050
400	0.100	0.100
405	0.200	0.200
410	0.400	0.400
415	0.800	0.800
420	0.900	0.900
425	0.950	0.950
430	0.980	0.980
435	1.00	1.00

440	1.00	1.00
445	0.970	1.00
450	0.940	1.00
455	0.900	1.00
460	0.800	1.00
465	0.700	1.00
470	0.620	1.00
475	0.550	1.00
480	0.450	1.00
485	0.400	1.00
490	0.220	1.00
495	0.160	1.00
500	0.100	1.00
505	0.079	1.00
510	0.063	1.00
515	0.050	1.00
520	0.040	1.00
525	0.032	1.00
530	0.025	1.00
535	0.020	1.00
540	0.016	1.00
545	0.013	1.00
550	0.010	1.00
555	0.008	1.00
560	0.006	1.00
565	0.005	1.00
570	0.004	1.00
575	0.003	1.0
580	0.002	1.0
585	0.002	1.0
590	0.001	1.0
595	0.001	1.0
600-700	0.001	1.0
700-1050	-	$10^{[(700-\lambda)/500]}$
1050-1400	-	0.2

Table C-9 – UV Radiation Exposure TLV and Spectral Weighting Function

Wavelength (nm)	TLV (J/m^2)	TLV (mJ/cm^2)	Relative Spectral Effectiveness, S_λ
180	2500	250	0.012
190	1600	160	0.019
200	1000	100	0.030
205	590	59	0.051
210	400	40	0.075
215	320	32	0.095
220	250	25	0.120
225	200	20	0.150
230	160	16	0.190
235	130	13	0.240
240	100	10	0.300
245	83	8.3	0.360
250	70	7.0	0.430
255	58	5.8	0.520
260	46	4.6	0.650
265	37	3.7	0.810
270	30	3.0	1.000
275	31	3.1	0.960
280	34	3.4	0.880
285	39	3.9	0.770
290	47	4.7	0.640
295	56	5.6	0.540
300	100	10	0.300
305	500	50	0.06
310	2000	200	0.015
315	$1.0*10^4$	1000	0.003
320	$2.9*10^4$	2900	0.0024
325	$6.0*10^4$	6000	0.00050
330	$7.3*10^4$	7300	0.00041
335	$8.8*10^4$	8800	0.00034
340	$1.1*10^5$	$1.1*10^4$	0.00028
345	$1.3*10^5$	$1.3*10^4$	0.00024
350	$1.5*10^5$	$1.5*10^4$	0.00020
355	$1.9*10^5$	$1.9*10^4$	0.00016
360	$2.3*10^5$	$2.3*10^4$	0.00013
365	$2.7*10^5$	$2.7*10^4$	0.00011
370	$3.2*10^5$	$3.2*10^4$	0.000093
375	$3.9*10^5$	$3.9*10^4$	0.000077
380	$4.7*10^5$	$4.7*10^4$	0.000064

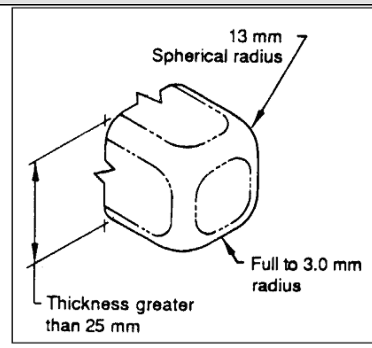
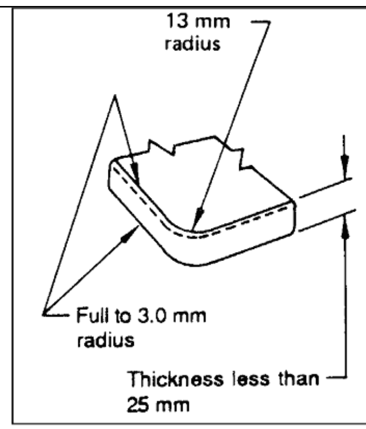
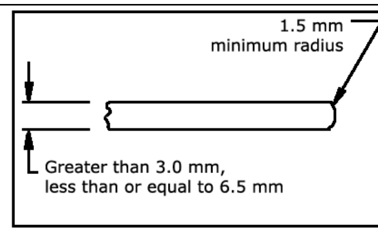
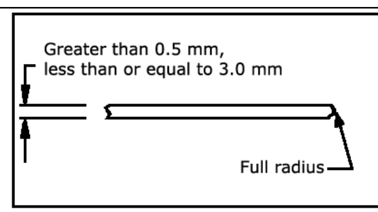
Wavelength (nm)	TLV (J/m^2)	TLV (mJ/cm^2)	Relative Spectral Effectiveness, S_λ
385	$5.7*10^5$	$5.7*10^4$	0.000053
390	$6.8*10^5$	$6.8*10^4$	0.000044
395	$8.3*10^5$	$8.3*10^4$	0.000036
400	$1.0*10^6$	$1.0*10^5$	0.000030

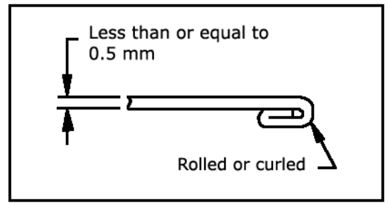
Table C-10 – Permissible Ultraviolet Exposures (200 – 400 nm)

Duration of Exposure per Day	Effective Irradiance, $\mu W/cm^2$
8 hrs.	0.1
4 hrs.	0.2
2 hrs.	0.4
1 hr.	0.8
30 min.	1.7
15 min.	3.3
10 min.	5
5 min.	10
1 min.	50
30 sec.	100
10 sec.	300
1 sec.	3000
0.5 sec.	6000
0.1 sec.	30000

Appendix D – Safety

Table D-1 Corner and Edge Rounding Requirements

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 (0.125 in).	
6.5 mm < t ≤ 25 mm (0.25 in. < t ≤ 1 in.)	13 mm (0.5 in.)	3.0 mm (0.125 in.)	
3.0 mm < t ≤ 6.5 mm (0.125 in. < t ≤ 0.25 in.)	6.5 mm 0.25 in.	1.5 mm (0.06 in.)	
0.5 mm < t ≤ 3.0 mm (0.02 in. < t ≤ 0.125 in.)	6.5 mm 0.25 in.	Full radius	

Material Thickness, t	Minimum Corner Radius	Minimum Edge Radius	Figure
t < 0.5 mm (t < 0.02 in.)	6.5 mm (0.25 in.)	Rolled, curled, or covered to 3.0 mm (0.125 in.)	

Appendix E – Thermal Comfort and Metabolic Loads

Thermal Comfort: Human comfort without use of thermal protective garments requires a fairly narrow temperature range. The comfort zone is defined as the range of environmental conditions in which humans can achieve thermal comfort and can perform routine activities without the negative effects of thermal stress. Thermal comfort is affected by work rate, clothing, and state of acclimatization. Figure E-1 is a graphical representation of the comfort zone. The comfort zone does not include the entire range of conditions in which humans can survive indefinitely. The indefinite survival zone is larger, and might require active perspiration or shivering, responses which are initiated by elevated or lowered core temperatures. Operation outside the comfort zone may be associated with performance decrements. The graph implies minimal air movement and assumes the radiant temperature of the surrounding environment is at the dry bulb temperature. The effects of acclimatization, work, and heavier clothing are shown as data trends by the arrows on the graph. This temperature range has been used successfully for STS and ISS vehicular operations.

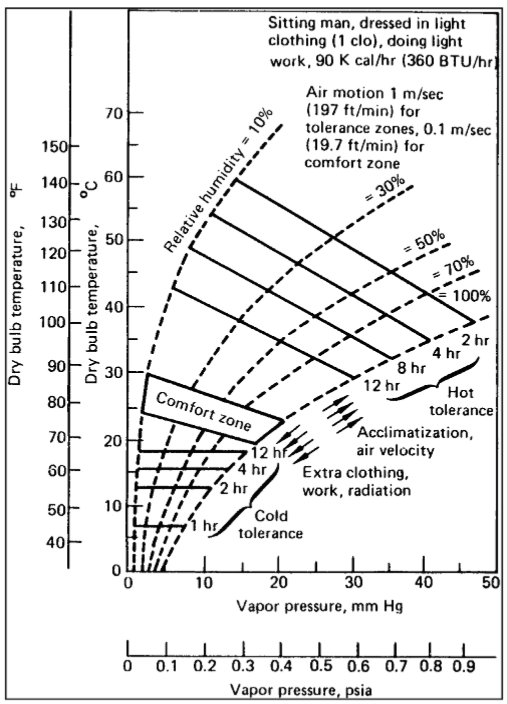


Figure E-1 Environmental Comfort Zone

Heat Storage and Rejection: The thermal comfort objective is to maintain body thermal storage within the comfort zone defined by the equation:

$$Qstored = \frac{MR - 278}{13.2} \pm 65\,\text{Btu}$$

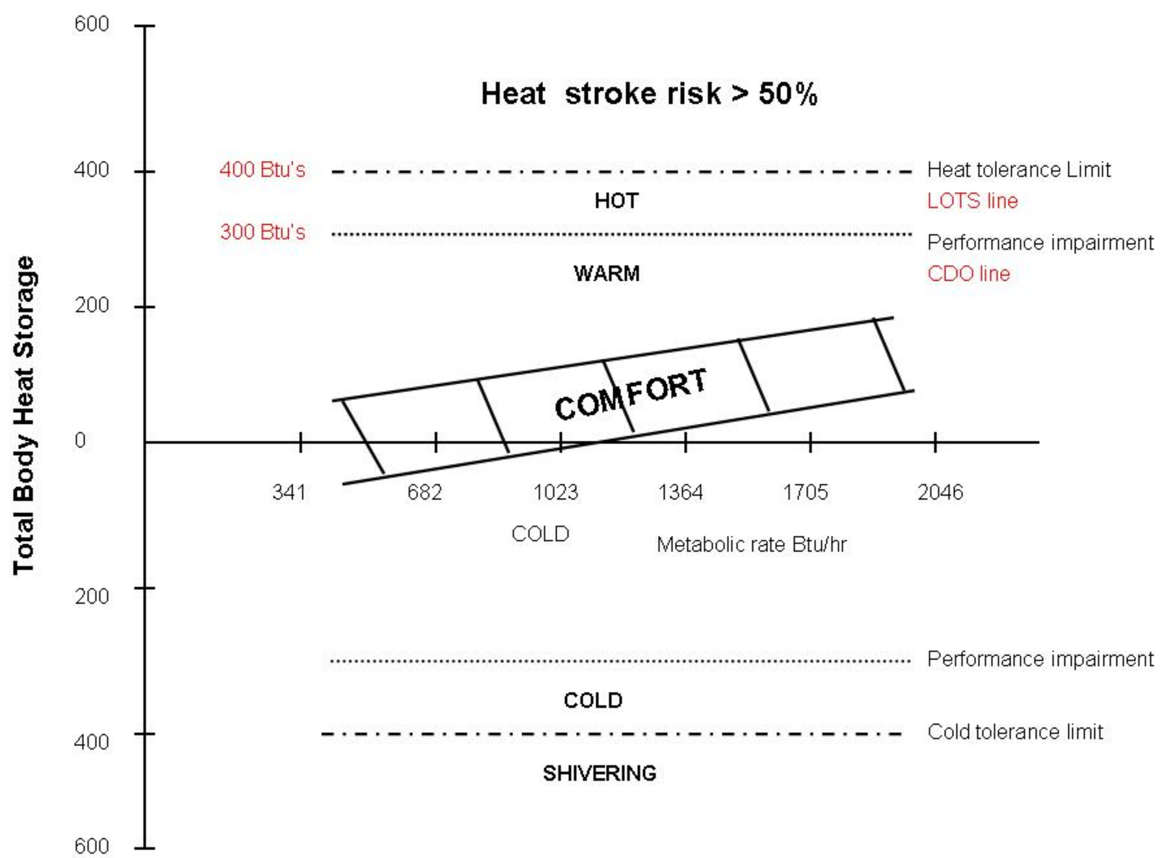
where MR = Metabolic Rate in Btu/hr

(this calculation can be converted to joules using the conversion 1 Btu = 1055.056 J)

Accepted means of heat storage or rejection (Q stored) calculation is per 41-Node man or Wissler model. The Q stored equation is plotted in Figure E-2 to graphically show the boundaries of human heat storage and rejection tolerance. During those portions of a mission when cabin conditions can not be maintained within nominal limits, short periods of departure from the comfort zone can be accommodated by crewmembers through heat storage or loss, not to exceed:

4.7 kJ/kg (2 Btu/lb) > Q stored > -4.1 kJ/kg (-1.76 Btu/lb)

Figure E-2 Heat Storage



Heat storage: A vehicular cabin with excess heat load may quickly reach crew tolerance limits and impair crew performance and health. Crew impairment begins when pulse is greater than 140 bpm or when skin temperature increases more than 1.4 ºC (2.5 ºF) (0.6 ºC (1 ºF) core), which correlates with heat storage of approximately 320 kJ (300 Btu). Table E-1 identifies core temperature range limits and associated performance decrements. Maintaining crewmember heat storage below the performance impairment level (Figure E-2) allows the crew the ability to conduct complex tasks without heat-induced performance degradation. Precise prediction of crew tolerances and time constraints for entry are not possible, therefore environmental temperature must be controlled.

In a non-acclimatized individual, water loss is approximately 0.95 L (32 oz) per hour and salt loss is approximately 2 to 3 grams (0.0044 to 0.0066 lb) per hour. In microgravity and elevated humidity, sweat forms an insulating layer over the body, further adding to the heat stress instead of relieving it. Losses may be less in a thermally acclimatized individual.

Heat rejection: If heat is removed from the body to the point of thermogenic shivering, crew task performance will be impaired, in a similar fashion to excess heat storage. Like the condition of excess heat storage, which can be mitigated by specialized cooling garments, excess heat rejection can be mitigated to some degree by the use of insulating garments. Figure E-1 shows the effect of tolerance to cold temperature and wind by the addition of varying degrees of thermal protecting clothing. Keeping crewmember heat rejection above the performance impairment level (Figure E-2) allows the crew to conduct tasks without cold-induced performance degradation, which occurs at approximately -280 kJ (-265 Btu).

Table E-1 Core Temperature Range Limits and Associated Performance Decrements

CORE TEMPERATURE °C (°F)	EQUIVALENT HEAT STORAGE KILOJOULES (BTU)	MEDICAL CONDITION
37.7-38.2 (99.9-100.8)	317-422 (300-400)	COGNITIVE TASK DECREMENT ONSET DECREASING MANUAL DEXTERITY DISCOMFORT HYPERTHERMIA/HEAT STRESS
38.2-39.2 (100.8-102.6)	422-633 (400-600)	SLOWED COGNITIVE FUNCTION INCREASED ERRORS IN JUDGMENT LOSS OF TRACKING SKILLS 25% RISK OF HEAT CASUALTIES POSSIBLE HEAT EXHAUSTION
39.2-39.6 (102.6-103.3)	633-844 (600-800)	FUNCTIONAL LIMIT OF PHYSICAL TASKS 50% RISK OF HEAT CASUALTIES PROBABLE HEAT EXHAUSTION POSSIBLE HEAT STROKE
>40 (>104)	>844 (>800)	100% RISK OF HEAT CASUALTIES PROBABLY HEAT STROKE

In summary, the thermal comfort objectives are that 1) body thermal storage be within the comfort zone, 2) evaporative heat losses be limited to insensible evaporation of moisture produced only by respiration and diffusion through the skin without active sweating, 3) there is no thermogenic shivering, and 4) body core temperatures are maintained near the normal resting values of approximately 37 °C (98°F), and 5) skin temperatures are maintained near normal resting values of approximately 32.8° to 34.4°C (91° to 94°F) when no liquid cooling garments (LCG) are used. During LCG use, skin temperatures will be significantly lower.

Expected Metabolic Loads: In order to allow calculation of vehicle environmental control system capacity, it is necessary to know expected crewmember metabolic loads, which will be affected by the magnitude of work being performed. Table E-2 provides estimates of metabolically generated heat (column 5), water (column 6), and CO_2 (column 8). This table was populated with physiologically measured parameters as well as 41-Node man simulations. These are expected crew induced loads based on the assumptions and conditions stated in the legend, and therefore will be altered if any of these variables change.

Table E-2: Crew Induced Metabolic Loads for a Standard Mission Day. The data represent crew induced loads from a single crewmember. In addition to any vehicle and equipment induced loads, the vehicle must accommodate crew induced loads for the entire crew, assuming only one crewmember can exercise at a time, and assuming that other crewmembers will be at nominal activity level during that time. Each crewmember must be able to exercise at this level once per day. Total heat output from a single crewmember is the sum of sensible (dry) heat and wet heat outputs. The sensible (dry) heat component includes only direct radiation and convection of heat from a crewmember. Total wet heat includes two components: 1) latent heat, including heat in water vapor which is exhaled and that of which evaporates directly from the skin, and 2) sweat run-off which includes heat in sweat which leaves the body in the form of liquid. For purposes of vehicle design modeling, O_2 consumption and CO_2 output are considered to be at 75% VO_2 max level during exercise, and return to nominal values when exercise has stopped. Water, O_2, and CO_2 are reported as kilograms and pounds mass, with O_2 and CO_2 converted from STPD data. The table data assumes an 82 kg (181 lb)crewmember, a 30 minute exercise period, VO_2max = 45 mL/kg/min (1.25 in^3/lb/min) at STPD, 5% work efficiency of the exercise device, air and wall temperature = 21° C (70° F), air flow = 9.1 m/min (30 ft/min), dew point = 10° C (50° F), vehicle pressure = 70.3 kPa (10.2 psi), 0 g loading, respiratory quotient = 0.92 (must be applied volumetrically), and crewmember wearing shorts and t-shirt. If any of the above conditions or assumptions change, the described loads will be altered.

1 Crewmember Activity Description	2 Duration of Activity (hr)	3 Sensible (dry) Heat Output kJ/hr (Btu/hr)	4 Wet Heat Output (includes latent and sweat run-off) kJ/hr (Btu/hr)	5 Total Heat Output Rate kJ/hr (Btu/hr)(2)	6 Water Output kg/min*10^{-4} (lbm/min*10^{-4})	7 O_2 Consumption kg/min*10^{-4} (lbm/min*10^{-4})	8 CO_2 Output kg/min*10^{-4} (lbm/min*10^{-4})
Sleep	8	224 (213)	92 (87)(1)	317 (300)	6.30 (13.90)	3.71 (8.183)	4.71 (10.38)
Nominal	14.5	402 (381)	126 (119)(1)	528 (500)	8.66 (19.10)	6.28 (13.85)	7.86 (17.32)
Exercise 0 – 15 min at 75% VO_2max	0.25	514 (487)	692 (656)	1206 (1143)	47.72 (105.20)	39.40 (86.86)	49.85 (109.90)

Exercise 15 – 30 min at 75% VO_2max	0.25	624 (591)	2351 (2228)	2974 (2819)	161.89 (356.90)	39.40 (86.86)	49.85 (109.90)
Recovery 0 -15 min post 75% VO_2max	0.25	568 (538)	1437 (1362)	2005 (1900)	99.02 (218.30)	6.28 (13.85)	7.86 (17.32)
Recovery 15 – 30 min post 75% VO_2max	0.25	488 (463)	590 (559)	1078 (1022)	40.60 (89.50)	6.28 (13.85)	7.86 (17.32)
Recovery 30 – 45 min post 75% VO_2max	0.25	466 (442)	399 (378)	865 (820)	27.40 (60.40)	6.28 (13.85)	7.86 (17.32)
Recovery 45 – 60 min post 75% VO_2max	0.25	455 (431)	296 (281)	751 (712)	21.82 (48.10)	6.28 (13.85)	7.86 (17.32)
Total Per Day(3)	24	8406 (7967)	3997 (3788)	12401 (11754)	1.66 (3.65)(3)	0.880 (1.94)(3)	1.11 (2.44)(3)

(1) These values do not include a sweat run-off component, as none is expected.
(2) This column will reflect a lag between metabolic rate and heat output.
(3) No multipliers are applied to this row.

Suited Operations: Suited operations encompass a diverse set of activities that result in varied metabolic rates. Under certain conditions, the vehicle may need to support these metabolic loads through umbilical connections. Table E-3 contains ranges of metabolic rates expected during suited operations, although this table will evolve as the operations concept matures. These data should therefore only be used as historical reference and in progress estimates, and not as design goals.

Table E-3: Crewmember Metabolic Rates for Suited Operations kJ/hr (Btu/hr)

Data Source	Minimum	Average	Maximum(1)
µ Gravity EVA (ISS and STS)	**575 (545)(2)**	**950 (900)(3)**	**2320 (2200)**
Apollo Lunar Surface EVA	**517 (490)(2)**	**1030 (980)**	**2607 (2471)**
Advanced Walkback Test(4)	**1767 (1675)(1)**	**2505 (2374)**	**3167 (3002)**

(1) transient condition less than 15 min in duration, individual instance

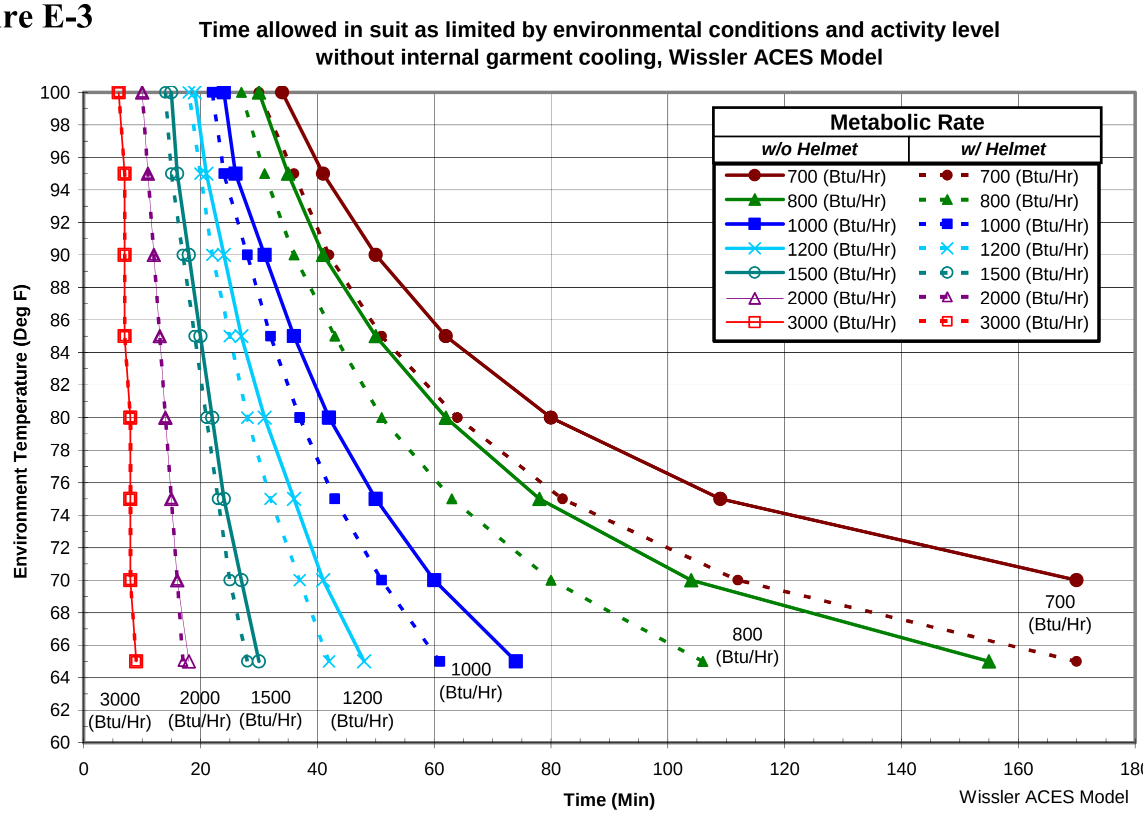
(2) minimum average for low activity EVA durations

(3) includes Orlan ISS EVAs, which trend to slightly higher metabolic rates

(4) simulated 10 km (6.2 mile) lunar surface walk requiring 1-2 hours to complete, in case of rover failure, n=6

When a crewmember is in a suit with no active cooling, heat storage may increase rapidly. JSC thermoregulatory models (Wissler & 41-Node man) simulating hot cabin entries wearing launch and entry suits with the thickness, conductance, wickability, and emmissivity properties of the Advanced Crew Escape Suit (ACES) predicted loss of body cooling mechanisms. Data from military aircrew protective ensembles also found that body temperature increases more rapidly over time in pressure suits when compared to a shirt-sleeve environment. Figure E-3 provides the time allowance in a suit (without active cooling) prior to the onset of cognitive impairment.

Figure E-3



Appendix F – Acronyms

ANSI	American National Standards Institute
CEV	Crew Exploration Vehicle
CFE	Contractor-Furnished Equipment
DoD	Department of Defense
DSNE	Design Specification for Natural Environments
ECLS	Environment Control and Life Support
EVA	Extravehicular Activity
GCR	Galactic Cosmic Ray(Radiation)

GFE	Government Furnished Equipment
IRD	Interface Requirements Document
ISO	International Standards Organization
ISS	International Space Station
IVA	Intra-Vehicular Activity
LET	Linear Energy Transfer
LOC	Loss of Crew
LOM	Loss of Mission
LRU	Line Replacement Unit
LSAM	Lunar Surface Access Module
MMOD	Micrometeoroids and Orbital Debris
NPR	NASA Procedural Requirement
ORU	Orbital Replacement Unit
RF	Radio Frequency
SPE	Solar Particle Event
USAF	United States Air Force

Appendix G – Glossary

<RESERVED>

Appendix H – TBD List

TBD	HSIR Req.	Closure Plan	Target Date
TBD-006-001	HS3098A HS3098AV	The intent of this TBD is to arrive at a single threshold radiance value for several requirements in order to exclude most light sources from unnecessary and expensive validation testing while maintaining a comfortable safety margin. This TBD is being resolved through the research of current industrial standards and comparison of threshold levels that consider all damage pathways. Once a common threshold level is identified and a safety margin is determined, the TBD can be closed.	1/15/2007
TBD-006-002	HS3099A HS3099AV	The intent of this TBD is to arrive at a single threshold radiance value for several requirements in order to exclude most light sources from unnecessary and expensive validation testing while maintaining a comfortable safety margin. This TBD is being resolved through the research of current industrial standards and comparison of threshold levels that consider all damage pathways. Once a common threshold level is identified and a safety margin is determined, the TBD can be closed.	1/15/2007
TBD-006-003	HS3101A HS3101AV	The intent of this TBD is to arrive at a single threshold radiance value for several requirements in order to exclude most light sources from unnecessary and expensive validation testing while maintaining a comfortable safety margin. This TBD is being resolved through the research of current industrial standards and comparison of threshold levels that consider all damage pathways. Once a common threshold level is identified and a safety margin is determined, the TBD can be closed.	1/15/2007

TBD-006-005	HS3104A HS3104AV	The intent of this TBD is to arrive at a single threshold radiance value for several requirements in order to exclude most light sources from unnecessary and expensive validation testing while maintaining a comfortable safety margin. This TBD is being resolved through the research of current industrial standards and comparison of threshold levels that consider all damage pathways. Once a common threshold level is identified and a safety margin is determined, the TBD can be closed.	1/15/2007
TBD-006-008	HS6091 HS6091V	The nominal operating pressure of the vehicle is needed prior to determining the pressure and gaseous composition for denitrogenation. Once the nominal vehicle operating pressure is determined, analysis will be performed to determine optimum pressures and gesous compositions for denitrogenation and concurrence will be needed between the EVA Physiology, Systems and Performance (EPSP) and the EVA Integrated Product Team (IPT).	9/15/2007
TBD-006-013	HS7063D HS7063DV	The emergency coding table will be developed in conjunction with the CEV Human Systems Integration Team.	PBS
TBD-006-014	HS9032 HS9032V	A study will be conducted to determine distinct auditory annunciations for emergency, caution, and warning event classes. Participants will include ARC Human System Integration Division and the JSC Habitability and Human Factors office.	10/15/2007
TBD-006-021	HS3103A HS3103AV	The intent of this TBD is to arrive at a single threshold radiance value for several requirements in order to exclude most light sources from unnecessary and expensive validation testing while maintaining a comfortable safety margin. This TBD is being resolved through the research of current industrial standards and comparison of threshold levels that consider all damage pathways. Once a common threshold level is identified and a safety margin is determined, the TBD can be closed.	1/15/2007
TBD-006-050	HS10028	Discussion with stakeholders from Projects and Ground Operations.	9/15/2007

TBD-006-051	HS7063V	Literature reviews and pilot interviews will be conducted by personnel in the JSC Habitability and Human Factors Office to determine appropriate input-output mapping for the compatibility table.	PBS
TBD-006-052	HS3065A HS3065AV	Discussion with subject matter experts at Wright Patterson AFB	PBS
TBD-006-053	HS6013	Research is required to determine the expected incidence of motion sickness on the lunar surface	2010

Appendix I – TBR List

TBR	HSIR Req.	Closure Plan	Target Date
TBR-006-030	HS2001	Presenting results of anthropometry analysis to the Program.	PBS
TBR-006-002	HS2002	Presenting results of anthropometry analysis to the Program.	PBS
TBR-006-003	HS2009	This TBR will be removed by PBS once the requirement is either removed, or rewritten to point to the Loads Data Book while keeping words to indicate protection of the crew from hazards	PBS
TBR-006-004	HS3006D	Additional analysis required to determine the contaminant size.	PBS
TBR-006-005	HS3006D	Closure steps include: 1) study the physicochemical properties of lunar dust; 2) determine how to activate dust and simulants; 3) develop methods for and conduct toxicological studies, and 4) review all data via expert panel to establish the exposure standard.	2010
TBR-006-006	HS3028 HS3028V	The personal hygiene system must be designed prior to analyzing the quantity of water required for personal hygiene.	9/15/2008
TBR-006-018	HS3051	Historical usage of temperature set points during manned spaceflight are being researched. If there is no indication of significant usage below 70 F, the TBR will be considered resolved and the lower limit of adjustability will remain at 70 F. If set points have been routinely used in a manner that would still be necessary with the new vehicle designs, further analysis may be required due to the mass, power, and volume constraints of a system that would be able to accommodate temperatures below 70 F.	1/15/2007

TBR-006-022	HS3081	1) Determine if there are credible noise sources for non-launch, entry, burn phases. 2) Perform literature research on ultrasonic noise effects on humans. 3) Discuss with experts (probably from military) regarding how they handle infrasonic noise. 4) Consider impulse noise requirement and whether or not this is adequate to guard against infrasonic impulse noise.	PBS
TBR-006-023	HS3086 HS3086V	CEV asked to put the TBR in the requirement to allow flexibility in the vehicle and instrument design. CEV felt that at this point it is not clear how much "landscape" or view angle will be available on the exterior of the vehicle. This will "get resolved" as both designs mature.	CEV PDR 2008
TBR-006-015	HS6081 HS6081V	Analysis is required to determine if indeed 22.7 psi vehicle pressure is sufficient to treat decompression sickness.	9/15/2007
TBR-006-016	HS6081 HS6081V	Analysis is required to determine if indeed 6 hours is a sufficient amount of time to treat decompression sickness.	9/15/2007
TBR-006-021	HS6059	Closure of this TBR requires concurrence by a Nutritional Panel comprised of intramural and extramural experts.	9/15/2007
TBR-006-024	HS7029	Discussions will be held with JSC Aeroscience and Flight Mechanics Division personnel to determine mission performance specifications for the vehicles	9/15/2007
TBR-006-025	HS7029V	An analysis will be performed by ARC Human System Integration Division to determine the appropriate performance degradation rate.	PBS
TBR-006-027	HS7028 HS7028V	A study will be conducted to determine reach envelopes for various g-levels. Participants will include the JSC Habitability and Human Factors office and ARC Human System Integration Division.	9/15/2007

TBR-006-029	HS7072 HS7072V	Research will be performed, in collaboration with the Software and Avionics Interoperational and Reuse (SAIR) System Integration Group (SIG) and the Programs, including the CEV Cockpit Team, to determine the appropriate number.	9/15/2007
TBR-006-031	HS6035	An exercise hardware device must be selected in order to define the required operational envelope.	9/15/2007
TBR-006-036	HS5034V	A design of the vehicle and the lighting system is needed to determine the measurement distance and locations for lighting.	9/15/2007
TBR-006-037	HS5052	This requirement is a should and does not require a verification, however the designer should have some objective pass-fail criteria for what is meant by International Safety Yellow. Determine an appropriate source for International Safety Yellow standard and cite as a resource.	PBS
TBR-006-038	HS6063	Analysis is required to determine if 946 mL (32 ounces) in the suit is adequate to support EVAs great than 4 hours and if it will be possible to carry that quantity within the suit.	11/29/2007
TBR-006-051	HS6097 HS6097V	Analysis is required to determine if 4 hours is an acceptable amount of time for delivery delay.	9/15/2007
TBR-006-052	HS6101	Closure of this TBR requires approval of the Space Flight Crew Health Standards Volume 1: Space Flight Crew Health Standards by NASA Headquarters.	PBS
TBR-006-053	HS6100	Analysis is required to determine if 8 psi is sufficient to treat decompression sickness within 20 minutes of symptom onset.	9/15/2007
TBR-006-054	HS7001 HS7001V	Discussions will be held to determine the appropriate TLX workload level. Participants will include the JSC Habitability and Human Factors office and ARC Human System Integration Division as well as other stakeholders.	PBS

TBR-006-055	HS7002 HS7002V	Discussions will be held to determine the appropriate TLX workload level. Participants will include the JSC Habitability and Human Factors office and ARC Human System Integration Division as well as other stakeholders.	PBS
TBR-006-056	HS7066V	Discussions will be held to determine the appropriate HSIR VR for usability requirements. Participants will include the JSC Habitability and Human Factors office and ARC Human System Integration Division as well as other stakeholders.	PBS
TBR-006-057	HS7076V	Discussions will be held to determine the appropriate ANSI standard to be used for speech intelligibility measurement methods.	PBS
TBR-006-058	HS7080 HS7080V	Discussions will be held to determine the appropriate TLX workload level. Participants will include the JSC Habitability and Human Factors office and ARC Human System Integration Division as well as other stakeholders.	PBS
TBR-006-059	HS7081V	Discussions will be held to determine the appropriate HSIR VR for usability requirements. Participants will include the JSC Habitability and Human Factors office and ARC Human System Integration Division as well as other stakeholders.	PBS
TBR-006-060	HS10008	Will work with KSC to determine appropriate database. Selection will depend upon understanding worker population and may thus require some data collection.	15-Jun-07
TBR-006-061	HS8004	Will collaborate with KSC, CLV, and CEV to determine appropriate number of technicians.	15-Jun-07
TBR-006-062	HS8004	Will collaborate with KSC, and with maintenance engineers to determine appropriate hours of task time.	16-Jun-07
TBR-006-063	HS7078 HS7078V	Literature reviews and pilot interviews will be conducted by personnel in the JSC Habitability and Human Factors Office to determine appropriate input-output mapping for the compatibility table.	PBS
TBR-006-064	HS7080V	Discussions will be held to determine the appropriate HSIR VR for workload requirements. Participants will include the JSC Habitability and Human Factors office and ARC Human System Integration Division as well as other stakeholders.	PBS

TBR-006-065	HS7001V	Discussions will be held to determine the appropriate HSIR VR for workload requirements. Participants will include the JSC Habitability and Human Factors office and ARC Human System Integration Division as well as other stakeholders.	PBS
TBR-006-066	HS7002V	Discussions will be held to determine the appropriate HSIR VR for workload requirements. Participants will include the JSC Habitability and Human Factors office and ARC Human System Integration Division as well as other stakeholders.	PBS
TBR-006-067	HS2005 HS2006	Presenting results of anthropometry analysis to the Program.	PBS
TBR-006-068	HS5030	Discussion with SMEs to determine if intent is covered in other documentation.	PBS
TBR-006-069	HS8051 HS8051V	Experts in Passive Thermal, ECLS, M&P, Environmental Factors, and Human Factors to determine time limit ensuring a vehicle that precludes condensation but also can handle it	PBS
TBR-006-070	HS2003 HS2003V HS2004 HS2004V	Presenting results of anthropometry analysis to the Program.	PBS
TBR-006-071	HS7081 HS7081V	Discussions will be held to determine the appropriate usability error rate for tasks that can result in loss of crew/vehicle/mission. Participants will include the JSC Habitability and Human Factors office and ARC Human System Integration Division as well as other stakeholders.	PBS
TBR-006-072	HS7066 HS7066V	Discussions will be held to determine the appropriate usability error rate for tasks that can result in loss of crew/vehicle/mission. Participants will include the JSC Habitability and Human Factors office and ARC Human System Integration Division as well as other stakeholders.	PBS
TBR-006-073	HS3029	1) identify the need for this requirement in the HSIR versus lower level document since the meal preparation requirement (3.5.1.2.3/HS6005) and incremental water delivery requirement to bound the water delivery rate, 2) determine the range of time that is required to deliver potable water for hygiene, food/drink hydration, sample collection, and EVA interfaces (drink bag and suit).	PBS

Appendix J – Allocation Matrix

This table denotes allocation of HSIR requirements to the various systems. Additionally, the last two columns denote which Verification Requirements must be satisfied with the Verification Requirements contained within the HSIR Section 4 (those marked L2) , OR which may be verified using alternate acceptable methods that have been Level 3 Project approved and documented (those marked L3). The Level 3 projects are not required to obtain approval for verification closure or changes to verification methodology beyond their own project boards when verification has been designated Level 3. Designation of Level 2 verification denotes that the Level 2 Program dictates and maintains change authority over the verification methodology, but does not necessarily imply that Level 2 performs the verification.

Requirements								Verifications	
Requirement #	CEV	LSAM	CLV	CaLV	MS	GO	EVA	L2	L3
HS10001	X	X	X	X					X
HS10002	X	X	X	X					X
HS10004	X	X	X	X					X
HS10006	X	X	X	X					X
HS10008	X	X	X	X					X
HS10009	X	X	X	X					
HS10010	X	X	X	X					X
HS10011	X	X	X	X					X
HS10012	X	X	X	X					X
HS10013	X	X	X	X					X
HS10014	X	X	X	X					X
HS10015	X	X	X	X					X
HS10017	X	X	X	X					X
HS10018	X	X	X	X					X
HS10019	X	X	X	X					X
HS10020	X	X	X	X					X
HS10021	X	X	X	X					X
HS10022	X	X	X	X					X
HS10023	X	X	X	X					
HS10024	X	X	X	X					X
HS10025	X	X	X	X					X
HS10026	X	X	X	X					
HS10027	X	X	X	X					X
HS10028	X	X	X	X					X
HS10029	X	X	X	X					X
HS10030	X	X	X	X					X
HS10031	X	X	X	X					X
HS10032	X	X	X	X					X
HS10033	X	X	X	X					X

Requirements								Verifications	
Requirement #	**CEV**	**LSAM**	**CLV**	**CaLV**	**MS**	**GO**	**EVA**	**L2**	**L3**
HS10039	X	X	X	X					X
HS10043	X	X	X	X					X
HS10045	X	X	X	X					X
HS10047	X	X	X	X					
HS10048	X	X	X	X					
HS10050	X	X	X	X					
HS10051	X	X	X	X					X
HS10052	X	X	X	X					X
HS10053	X	X	X	X					
HS10054	X	X	X	X					
HS2001	X	X							X
HS2002	X	X					X		X
HS2003	X	X							X
HS2004	X	X					X		X
HS2005	X	X							
HS2006	X	X					X		X
HS2007	X	X							X
HS2007B	X	X		X			X		
HS2008	X	X							X
HS2008B	X	X		X			X		
HS2009	X	X							X
HS3001	X	X			X				X
HS3004	X	X							X
HS3004B	X	X							X
HS3004C	X	X							X
HS3004D	X	X							X
HS3005	X	X					X		X
HS3005B	X	X					X		X
HS3005C	X	X							X
HS3006	X	X							X
HS3006B	X	X							X
HS3006C	X	X							X
HS3006D	X	X							X
HS3007	X	X							X
HS3009	X	X							X
HS3012A	X	X							X
HS3012B	X	X							X
HS3012C	X	X							X
HS3012D	X	X							X
HS3013	X	X							X
HS3014	X	X					X		X

Requirements								Verifications	
Requirement #	**CEV**	**LSAM**	**CLV**	**CaLV**	**MS**	**GO**	**EVA**	**L2**	**L3**
HS3015	X	X							X
HS3015A	X	X	X	X			X		X
HS3016	X	X							X
HS3017	X	X							X
HS3017A	X	X							X
HS3017B	X	X							X
HS3019	X	X							X
HS3019A	X	X							X
HS3025	X	X							X
HS3026	X								X
HS3027	X								X
HS3028	X	X							X
HS3029	X	X							X
HS3030	X	X							
HS3031	X	X							X
HS3032	X	X							
HS3034	X	X				X			X
HS3036	X	X							X
HS3037	X	X					X		X
HS3041	X	X							X
HS3046	X	X							X
HS3047	X	X							X
HS3050	X	X							X
HS3051	X	X							X
HS3051B	X	X			X				X
HS3052	X	X							X
HS3053	X	X							X
HS3054	X	X					X		X
HS3055	X	X							X
HS3059	X	X	X	X					X
HS3060		X							X
HS3061	X	X	X	X					X
HS3062	X	X	X	X					X
HS3064	X	X	X	X					X
HS3065	X	X	X	X					X
HS3065A	X	X	X	X					X
HS3069	X	X							X
HS3070	X	X	X	X					X
HS3071	X	X	X	X					X
HS3072	X	X	X	X			X	X	
HS3073	X	X	X	X			X	X	

Requirements								Verifications	
Requirement #	**CEV**	**LSAM**	**CLV**	**CaLV**	**MS**	**GO**	**EVA**	**L2**	**L3**
HS3074	X	X	X	X			X	X	
HS3075	X	X		X			X		X
HS3076	X	X		X			X	X	
HS3078	X	X		X			X		X
HS3079	X	X		X					X
HS3080	X	X		X			X	X	
HS3081	X	X		X			X	X	
HS3082	X	X					X		
HS3083	X	X					X	X	
HS3084	X	X							X
HS3085	X	X						X	
HS3086	X	X						X	
HS3088	X	X						X	
HS3089	X	X						X	
HS3090	X	X							X
HS3091	X	X							X
HS3092	X	X							X
HS3093	X	X	X	X			X	X	
HS3094	X	X		X				X	
HS3095	X	X		X				X	
HS3096	X	X		X				X	
HS3097	X	X		X				X	
HS3098	X	X						X	
HS3098A	X	X				X		X	
HS3099	X	X						X	
HS3099A	X	X				X		X	
HS3101	X	X						X	
HS3101A	X	X				X		X	
HS3103	X	X						X	
HS3103A	X	X				X		X	
HS3104	X	X						X	
HS3104A	X	X				X		X	
HS3105	X	X	X	X				X	
HS3106	X	X		X				X	
HS3107	X	X		X				X	
HS3108	X		X			X			X
HS3109	X	X							X
HS3110	X	X						X	
HS3111	X	X						X	
HS3112	X	X			X			X	
HS3113	X	X			X			X	

Requirements								Verifications	
Requirement #	**CEV**	**LSAM**	**CLV**	**CaLV**	**MS**	**GO**	**EVA**	**L2**	**L3**
HS3114	X	X							X
HS3115	X	X							X
HS3116	X	X							X
HS4002	X	X				X			X
HS4003	X	X							X
HS4004	X	X							X
HS4005	X	X				X			X
HS4006	X	X				X			X
HS4007	X	X							X
HS4008	X	X				X	X		X
HS4008B	X	X				X	X		X
HS4008C	X	X							X
HS4012	X	X				X	X		X
HS4019	X	X							X
HS4021	X	X				X			X
HS4022	X	X				X	X		X
HS5001	X	X							
HS5002	X	X							
HS5003	X	X							X
HS5004	X	X							X
HS5005	X	X							X
HS5006	X	X							
HS5007	X	X							X
HS5008	X	X							X
HS5009	X	X				X			X
HS5010	X	X				X			X
HS5012	X	X							X
HS5013	X	X				X			X
HS5014	X	X				X			X
HS5016	X	X							X
HS5017	X	X							X
HS5019	X	X							X
HS5021	X	X							X
HS5022	X	X							X
HS5027	X	X							X
HS5028	X	X							X
HS5028B	X	X							X
HS5030	X	X							
HS5031	X	X							X
HS5032	X	X							
HS5034	X	X							X

Requirements								Verifications	
Requirement #	**CEV**	**LSAM**	**CLV**	**CaLV**	**MS**	**GO**	**EVA**	**L2**	**L3**
HS5034B	X	X							X
HS5035	X	X							X
HS5039	X	X							X
HS5040	X	X							X
HS5041	X	X							X
HS5042	X	X							X
HS5043	X	X				X			X
HS5044	X	X				X			X
HS5045	X	X							X
HS5046	X	X							X
HS5048	X	X							X
HS5049	X	X							X
HS5050	X	X							X
HS5051	X	X							X
HS5052	X	X							
HS6001	X	X							
HS6002	X	X							
HS6003	X	X							X
HS6004	X	X							X
HS6005	X	X							
HS6009	X	X							X
HS6010	X	X							
HS6012	X	X							
HS6013	X	X							X
HS6014	X	X							X
HS6016	X	X							X
HS6017	X	X							X
HS6018	X	X							X
HS6020	X	X							X
HS6020C	X	X							X
HS6020D	X	X							X
HS6021	X	X							X
HS6022	X	X							X
HS6023	X	X							X
HS6024	X	X							X
HS6025	X	X							X
HS6025B	X	X							X
HS6027	X	X							X
HS6028	X	X							
HS6029	X	X							X
HS6030	X	X							X

Requirements								Verifications	
Requirement #	**CEV**	**LSAM**	**CLV**	**CaLV**	**MS**	**GO**	**EVA**	**L2**	**L3**
HS6031	X	X							
HS6032	X	X							X
HS6035	X	X							X
HS6036	X	X							X
HS6037	X	X							X
HS6038	X	X							X
HS6044	X	X							
HS6046	X	X							
HS6047	X	X							
HS6049	X	X							
HS6050	X	X							X
HS6051	X	X							X
HS6052	X	X							
HS6053	X	X							X
HS6054	X	X							
HS6056	X	X							X
HS6057	X	X							X
HS6058	X	X							X
HS6059	X	X							X
HS6060	X	X							X
HS6062		X					X		X
HS6063		X					X		X
HS6065	X	X							X
HS6069	X	X							
HS6073	X	X							X
HS6075	X	X			X				X
HS6076	X	X			X				X
HS6077	X	X					X		X
HS6078	X	X					X		X
HS6079	X	X							X
HS6080	X	X							X
HS6081	X	X					X		X
HS6082	X	X							X
HS6083	X	X							X
HS6084	X	X							X
HS6085	X	X							X
HS6086	X	X							X
HS6091	X	X							X
HS6095	X	X							X
HS6097	X	X							X
HS6099	X	X							X

Requirements								Verifications	
Requirement #	CEV	LSAM	CLV	CaLV	MS	GO	EVA	L2	L3
HS6100	X	X							X
HS6101	X	X							X
HS6102		X							X
HS6104	X	X							X
HS7001	X	X					X	X	
HS7002	X	X			X		X	X	
HS7003	X	X					X	X	
HS7004	X	X					X	X	
HS7007	X	X					X		
HS7009	X	X							X
HS7010	X	X							X
HS7010A	X	X							X
HS7018	X	X							
HS7018A	X	X							
HS7019	X	X					X		X
HS7021	X	X					X		
HS7021A	X	X					X		
HS7022	X	X					X		
HS7023	X	X					X		
HS7024	X	X					X		X
HS7027	X						X		X
HS7028	X						X		X
HS7029	X								X
HS7036	X	X					X		X
HS7044	X	X					X		X
HS7049	X	X							X
HS7049A	X	X							X
HS7055	X	X							X
HS7058	X	X							X
HS7058A	X	X							X
HS7058B	X	X							
HS7058C	X	X							
HS7058D	X	X							X
HS7058E	X	X							X
HS7059	X	X							X
HS7060	X	X							X
HS7060A	X	X							
HS7061	X	X							X
HS7063	X	X					X		X
HS7063A	X	X							X
HS7063B	X	X							

Requirements								Verifications	
Requirement #	**CEV**	**LSAM**	**CLV**	**CaLV**	**MS**	**GO**	**EVA**	**L2**	**L3**
HS7063C	X	X							X
HS7063D	X	X							X
HS7063E	X	X							X
HS7064	X	X	X	X		X	X		X
HS7065	X	X	X	X		X	X		X
HS7065A	X	X					X		X
HS7066	X	X					X	X	
HS7067	X	X					X		X
HS7070	X	X							X
HS7071	X	X							
HS7072	X	X						X	
HS7072A	X	X							X
HS7074	X	X							X
HS7075	X	X							X
HS7076	X	X					X		X
HS7077	X	X							X
HS7078	X	X	X	X			X		X
HS7079	X	X	X	X			X		X
HS7080	X	X					X	X	
HS7081	X	X					X	X	
HS7925	X	X							X
HS8001	X	X							X
HS8002	X	X							X
HS8003	X	X							X
HS8004	X	X	X	X					
HS8005	X	X							X
HS8006	X	X							X
HS8007	X	X							X
HS8008	X	X							X
HS8009	X	X							X
HS8010	X	X							X
HS8011	X	X	X	X					X
HS8013	X	X	X	X					X
HS8015	X	X							X
HS8016	X	X							X
HS8017	X	X							X
HS8018	X	X							
HS8020	X	X							X
HS8021	X	X							X
HS8022	X	X							X
HS8023	X	X							X

Requirements								Verifications	
Requirement #	**CEV**	**LSAM**	**CLV**	**CaLV**	**MS**	**GO**	**EVA**	**L2**	**L3**
HS8024	X	X							X
HS8026	X	X							
HS8029	X	X							X
HS8030	X	X							
HS8031	X	X							X
HS8032	X	X							X
HS8034	X	X							X
HS8037	X	X							
HS8041	X	X							X
HS8042	X	X							X
HS8043	X	X							
HS8045	X	X							X
HS8046	X	X							X
HS8047	X	X							X
HS8048	X	X	X	X					
HS8050	X	X							X
HS8051	X	X							X
HS8052	X	X					X		X
HS8053	X	X					X		
HS8054	X	X					X		X
HS9014	X	X					X		
HS9018	X	X							X
HS9019	X	X							X
HS9020	X	X							X
HS9021	X	X							X
HS9023	X	X							X
HS9025	X	X							X
HS9026	X	X							X
HS9027	X	X							X
HS9028	X	X							X
HS9029	X	X	X	X					X
HS9029A	X	X							X
HS9030	X	X							X
HS9032	X	X							X
HS9032A	X	X						X	
HS9037	X	X							X
HS9040	X	X							X
HS9041	X	X							X
HS9042	X	X						X	
HS9042A	X	X							X

Appendix K – Crew Interfaces

K1 Hardware and Software Controls – Compatibility of Movement

Reserved

Figure K-1 – Input-Output Compatibility

K2 Hardware and Software Controls – Coding for Emergency and Critical Controls

Reserved

Figure K-2 – Emergency Coding Table

K3 Caution and Warning – Aural Annunciations

Reserved

Figure K-3 – Caution and Warning Annunciation Table

Appendix L – Constellation Program Label Process and Requirements (TBR-006-063)

This annotated Table of Contents serves as a placeholder for future detailed labeling requirements. The current list provides scope of what the Label Process and Requirements Appendix will contain, but detailed information will be provided in a later revision of the HSIR.

TABLE OF CONTENTS

Appendix M – Window View Obstruction Keep-Out Zones

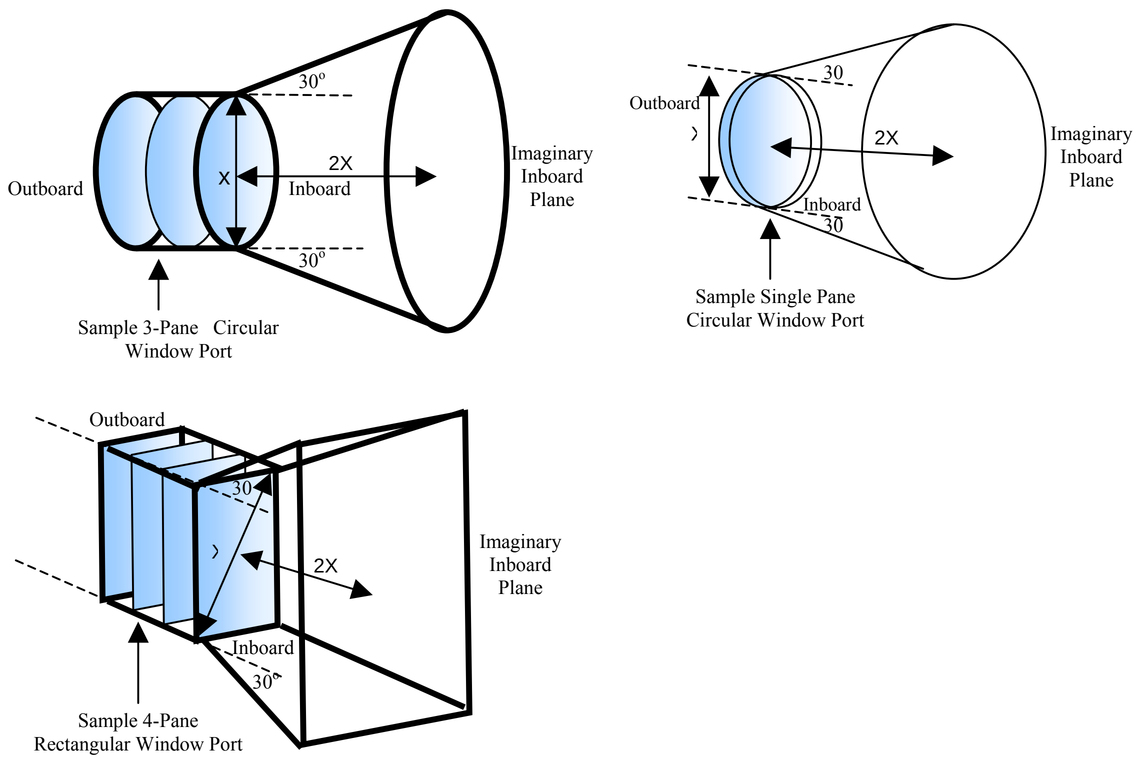


Figure M-1 - Window View Obstruction Keep-Out Zones.
Drawings are not to scale and are for illustrative purposes only.

Except for opaque shutters, protective covers, and shades so designed and intended to protect and cover the window when it is not in use, inner mold line/hull structure, and other windows; no hardware or equipment should obscure or obstruct the view through any window in any way from within a volume circumscribed by:

a. The perimeter of the clear viewing area of the outboard-most surface of the window.
b. The perimeter of the clear viewing area of the inboard-most surface of the window.
c. An imaginary plane located directly inboard from and parallel to the window panes at a distance equal to twice the largest clear viewing area dimension from the interior-most surface of the window but in no case less than 0.3 m (~1.0 ft) nor more than 1.5 m (~59 inches).
d. The surface that connects b and c above that slopes 30 degrees radially outward from the inboard facing normals to b above.

This exclusion shall include hardware and equipment for internal and external condensation prevention systems (CPS) and any other applied or installed instrumentation, except for small thermistors or other such sensors that are applied to the window itself within the outer-most 13 mm (~0.5 inch) of the clear viewing area, and in the case of Category B windows for hardware or equipment used in conjunction with piloting such as a Head's Up Display, Crew Optical Alignment System, or other similar equipment in which case any obstruction or obscuration of the view through the window from within this volume should be minimized (See Figure M-1).