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Human Landing System (HLS) Program Integrated Lander Verification Guidebook – Sustained Phase

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REVISION AND HISTORY PAGE

Revision No.	Change No.	Description	Release Date
Draft		Draft Release	06/25/21
Baseline	HLS-C0209	Initial Baseline Release (Reference HCB.02.02.2022)	02/04/22
Baseline	HLS-MD-0007	Update Sustain Requirements in HLS-VV-002 to "best available" based on requirement update recommendations to initial mission requirements.	03/10/22
Baseline	HLS-MD-0010	Updating definitions for sustaining/App P/SLD. The intent is to be consistent between SOW, DRDs, SRDs, and IRDs.	04/28/22
A	HLS-C0265	Updates based on Appendix P Industry feedback (Reference HCB.06.24.2022)	07/01/22

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1 Introduction

1.1 Scope and Purpose

Section 3 of this document offers general verification guidance on probabilistic success criteria that applies to verifications for all requirements in HLS-RQMT-006, Human Landing System (HLS) Program Integrated Lander Requirements Document – Sustained Phase.

Section 4 of this document provides baseline verifications for all Health and Medical Technical Authority (HMTA) requirements found in Appendix C of HLS-RQMT-006. They are verification methods intended for integrated system-level verification of performance or functionality. The Contractor may use these verifications directly in their verification, validation, and certification plan (VVCP) or offer tailoring of verification methods that, along with detailed verification objectives (DVOs), will provide sufficient evidence of compliance with the requirement as agreed upon with NASA.

Section 5 of this document provides baseline verifications for all Subsystem requirements found in Appendix E of HLS-RQMT-006. They are verification methods intended for integrated system-level verification of performance or functionality. The Contractor may use these verifications directly in their VVCP or offer tailoring of verification methods that, along with DVOs, will provide sufficient evidence of compliance with the requirement as agreed upon with NASA.

1.2 Measurement Units

Numerical data entered in shall be in International System of Units (SI) (metric) units with applicable tolerances. When appropriate the equivalent value in English Units should be added in parenthesis. Conversions between English and SI units shall be in accordance with NIST SP811, Guide for the Use of the International System of Units (SI).

2 Documents

For the purpose of this document, the term “document” can also refer to “digital artifacts,” “models,” or “viewpoints” as needed to convey and exchange configuration managed data or information.

2.1 Standards

The following documents may include specifications, models, standards, guidelines, handbooks, and other special publications that are called out in this document. These standards should be used as a basis for potential providers to build a proposal that will result in a human certifiable system.

Table 2-1: Health and Medical TA Documents

Document Number	Document Name
ACGIH TLVs® and BEIs®, 2014 (or later)	American Conference of Governmental Industrial Hygienists (ACGIH) standard for “Threshold Limit Values (TLVs®) and Biological Exposure Indices (BEIs®),” sections Infrasound and Low-Frequency Sound, Light and Near-Infrared Radiation, and Ultraviolet Radiation
ANSI/ASA S3.2-2009	Method For Measuring The Intelligibility Of Speech Over Communication Systems
ANSI Z136.1, 2014	“American National Standard for Safe Use of Lasers”, Table 5 (ocular) and Table 7 (dermal) without personal protective equipment.
HLS-PAP-001	HLS Physical Characteristics and Capabilities Dataset
HLS-STD-002	HLS Program GUI Standard
IEEE C95.1-2005	IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz
ISO 2631-1:1997(E)	Mechanical Vibration and Shock – Evaluation of Human Exposure to Whole-Body Vibration—Part 1: General Requirements
ISO 7731:2003(E)	Ergonomics -- Danger Signals for Public and Work Areas -- Auditory Danger Signals
JSC 20584	Spacecraft Maximum Allowable Concentrations (SMAC) for Airborne Contaminants
NASA/TM-2013-217380 REV1	Application of the Brinkley Dynamic Response Criterion to Spacecraft Transient Dynamic Events
SSP 30573	Space Station Program Fluid Procurement and Use Control Specification
TOX-VER-2016-03	Volatile Combustion Product Monitoring in Spacecraft

3 General Verification Guidance on Probabilistic Success Criteria

All requirements that specify a specific quantitative value or target generally require that a statistical basis be used in determining the subsequent verification success criteria. This is typically required for verifying the performance of electrical or mechanical systems that need to provide a particular function for the system. HLS recommends that a consistent set of probabilistic success criteria be utilized across the program wherever applicable. The recommended HLS probabilistic criteria (Table 3-1 below) are based on experience from past programs such as Space Shuttle, ISS, CCP and Constellation.

TABLE 3-1: HLS PROBABILISTIC CRITERIA

Requirement Type:	Probabilistic Success Criteria:
For nominal (i.e. no-fail) requirements	99.73% probability of success with 90% confidence
For contingency, off-nominal, requirements	95% probability success with 90% confidence
For lower priority requirements	90% probability of success with 90% confidence

Note that the second case for contingency or off-nominal requirements are associated with scenarios that are less likely than the nominal mission scenarios and therefore can have a reduced success criteria compared to the nominal mission cases. But contingency or off-nominal scenarios may still be strong drivers on design.

The third case for lower priority requirements applies to scenarios that do not directly support the primary mission objectives and therefore should not drive the design. Using the nominal/contingency success criteria may place too much emphasis for these cases. Typically these are scenarios that do not require added functionality or the allocation of additional consumables to mission. Additionally as a rule of thumb, a value of 90% will also generally provide good confidence for Monte Carlo or acceptance sampling analyses.

For situations where probabilistic success criteria are appropriate but the above guidelines are overly constraining or not directly applicable, the following should be considered in determining probability and confidence levels:

1. Whether the requirement is for nominal or contingency scenarios;
2. Safety consequences of not meeting the requirement;
3. Priority of the requirement e.g. whether the requirement is associated with primary or secondary mission objective(s);
4. Achievability of the required probability of success.

The rationale for use of different probabilities of success and confidence levels needs to be fully documented.

4 Human Health and Performance Verifications

Verification requirements include the method(s) for verification (e.g., test and analysis), the purpose of the verification method(s), and the criteria for assessing the success of the verification method(s). Verification requirements take into account the specific design, relevant development and flight experience, and overall Integrated Lander plan for certification. Successfully implementing the methods defined in the verification requirements will enable the Integrated Lander Provider to achieve certification by reducing the risk to a residual level acceptable by NASA.

Integrated Lander Providers are responsible for verification planning and the performance of verification activities as specified in section 4.1, below. The Integrated Lander Providers will produce verification evidence for compliance with all applicable requirements.

Verifications are performed to evaluate the system relative to an attribute established by the requirement. The evaluations must ensure capabilities are evaluated within all the constraints established by HLS-RQMT-006, applicable laws and regulations. Thus, test, analyses, and demonstrations must consider the full required operating envelope, environments, other interfacing elements, and range of states of the system when formulating the evaluation conditions.

4.1 Human Capabilities and Characteristics

V-HLS-S-HMTA-0002 Accommodate Physical Characteristics of Crew

Statement: Inspection, Analysis, Demonstration.

Anthropometry Dimensions and Range of Motion. Crew task analysis shall identify the postures, body motions, and anthropometric dimensions, including spinal lengthening associated with weightlessness and fractional gravity, applicable to crew task performance. Integrated task and worksite analysis, using drawings or CAD modeling, shall be performed on all crew functional areas to confirm that the design of crew interfaces for task performance accommodates the crew postures, range of motions, and range of applicable anthropometric dimensions. HITL demonstration shall utilize a flight representative mockup in the flight configuration with subjects in flight configurations (which will include emulation of suits and restraints as indicated) performing select tasks, as agreed to through JTP, to evaluate anthropometric and range of motion accommodation. Where the full anthropometric range (min through max) cannot be evaluated in worksite analysis or HITL demonstration, population analysis shall be performed to evaluate any limitations to crew accommodation or task performance.

Verification Success Criteria: The verification of anthropometry dimensions and range of motion shall be considered successful when analysis and demonstration show that crew physical characteristics as defined in HLS-PAP-001 Physical Characteristics and Capabilities Dataset are applied to the design of crew accommodations and interfaces for task performance.

Body Mass. Analysis shall be performed to confirm that body mass data as defined in HLS-PAP-001 Physical Characteristics and Capabilities Dataset are accommodated in the design of structures and equipment that will support crew mass under expected gravity and acceleration conditions through all mission phases.

Verification Success Criteria: The verification of body mass shall be considered successful when analysis shows that crew body mass as defined in HLS-PAP-001 Physical Characteristics and Capabilities Dataset are applied to the design of crew accommodations and interfaces for expected gravity and acceleration conditions through all mission phases.

Strength. Analysis and/or Test. Crew task analysis shall identify the crew postures, task motions, and Types of Strength applicable to crew task performance. Integrated task and worksite analysis shall be performed on all crew actuated interfaces to confirm that the design of crew-actuated mechanisms accommodates the Minimum Crew Operational Load for the appropriate operation criticality and withstands the Maximum Crew Operational Load as defined in HLS-PAP-001 Physical Characteristics and Capabilities Dataset. Test shall utilize a flight representative mockup in the flight configuration to measure the forces required to operate mechanical crew interfaces such as cranks, fasteners, switches, and buttons.

Verification Success Criteria: The verification of design for operational strength shall be considered successful when test shows the mechanical crew interfaces can be operated with the minimum crew operational load for the appropriate operation criticality and can withstand the Maximum Crew Operational Load as defined in HLS-PAP-001 Physical Characteristics and Capabilities Dataset.

V-HLS-S-HMTA-0012 Nominal Cognitive Workload

Statement: Test. The cognitive workload for nominal crew tasks shall be verified by test. The test for nominal cognitive workload shall consist of tasks from the crew task analysis that are jointly agreed upon by the provider and the JTP. The test shall consist of an evaluation by at least ten (10) trained personnel who are crew or designated crew representatives performing each of the listed crew tasks in a flight-like simulator or mockup (i.e., a facility that is determined to be as close to flight like as is possible) and providing workload ratings on the Bedford Workload Scale. Tasks shall be performed as operationally planned in ‘test-like-you-fly’ manner. When tasks are designed to be performed by multiple crewmembers, multiple personnel shall participate in the test and provide individual workload ratings. The evaluation period for each operational task sequence shall span the duration of the expected in-flight operation with personnel

providing their ratings at the end so as not to interrupt task flow. During workload evaluation tests, personnel will maintain performance error rates and completion times commensurate with the performance requirements of the particular task.

Workload must be assessed repeatedly by highly trained individuals using a consistent methodology immediately following dynamic human-in-the-loop simulations of tasks. A key element of testing in a flight-like simulator or mockup is that the simulated capabilities provide 'test like you fly' interfaces and functionality for accurate assessments of the capabilities under test. Workload should also be assessed in the design phase, prior to verification (including multi-dimensional tools such as the NASA-TLX), to ensure that the design or task does not induce unnecessary workload. The Bedford scale is appropriate for verification because it provides anchors for every rating, is familiar to the crew population, and provides a decision gate in which ratings above this gate are indicative of workload that is not satisfactory without a reduction in spare capacity. When using the Bedford scale, each subject must be briefed as to what each of the ratings on the scale mean, the task they are rating, the time period over which to make the rating, and the other tasks for which they need to judge their spare capacity. These items need to be consistent across subjects for each task. The Bedford scale is not linear, and the underlying distribution is not predicted to be normal, thus calculation of a mean and median or the uses of parametric statistics are not appropriate. An acceptable verification level of workload is a rating of 3 or less for critical or frequent tasks, and 6 or less for infrequent, non-critical tasks.

Verification Success Criteria: The verification shall be considered successful when the analysis in conjunction with the test results show that for representative nominal tasks identified in the analysis, at least 7 of the 10 ratings are no greater than a rating of 3 on the Bedford workload scale, while up to 3 of the 10 ratings may exceed the rating of 3 (allowing workload ratings of 4, 5, or 6 on the Bedford workload scale). For any ratings of 4, 5, or 6, a consensus must be reached by all of the participants indicating that the workload is acceptable in order for verification to be considered successful.

V-HLS-S-HMTA-0013 Off-Nominal Cognitive Workload

Statement: Test. The cognitive workload for off-nominal crew tasks shall be verified by test. The test for off-nominal cognitive workload shall consist of tasks from the crew task analysis that are jointly agreed upon by the provider and the JTP. The test shall consist of an evaluation by at least ten (10) trained personnel who are crew or designated crew representatives, and are representative of the crew population performing each of the listed crew tasks in a flight-like simulator or mockup (i.e., a facility that is determined to be as close to flight like as is possible) and providing workload ratings on the Bedford Workload Scale. Tasks shall be performed as operationally planned in 'test-like-you-fly' manner. When tasks are designed to be performed by multiple crewmembers, multiple personnel shall participate in the test and provide individual workload ratings. The evaluation period for each operational task sequence shall span the duration of the of expected in-flight operation with personnel providing their ratings at the end so as not to interrupt task flow. During workload evaluation tests, personnel will maintain

performance error rates and completion times commensurate with the performance requirements of the particular task.

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

Verification Success Criteria: The verification shall be considered successful when the analysis in conjunction with the test results show that for representative off-nominal tasks identified in the analysis, all of the subjects provide a rating of 6 or less on the Bedford scale.

4.2 Natural and Induced Environments

4.2.1 Cabin Atmosphere

V-HLS-S-HMTA-0015 Trend Analysis of Environmental Data

Statement: Analysis and Test. The ability of the Integrated Lander to provide environmental monitoring data at the specified rates shall be verified by test and analysis. The analysis shall include a review of the Integrated Lander software and be supported by component certification data to assess the rate at which the Integrated Lander samples and transmits the environmental data specified in HLS-RQMT-006, Table C-1: Sampling Rates for Trending Environmental Data.

Verification Success Criteria: The verification shall be considered successful when the analysis and test data show the Integrated Lander samples and transmits the appropriate environmental data at the rates specified in HLS-RQMT-006, Table C-1: Sampling Rates for Trending Environmental Data.

V-HLS-S-HMTA-0016 Inert Diluent Nitrogen Gas for Cabin Atmosphere

Statement: Analysis. The maintenance of a cabin atmosphere with nitrogen as the diluent gas shall be verified by analysis. The analysis shall include a review of the vehicle design including atmospheric constituent control setpoints and availability of consumables.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that the vehicle uses nitrogen as the diluent gas while maintaining all other key atmospheric constituents correctly.

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

Statement: Analysis and Test. The maintenance of oxygen partial pressure shall be verified through analysis of integrated, hardware/software, ECLSS subsystem functionality and performance, supported by test. Test generated data used by the analysis shall include oxygen system component certification data. Analysis shall also include generated data from ECLSS control software functional, performance, and interface testing.

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

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

Statement: Analysis and Test. The maintenance of carbon dioxide partial pressure shall be verified through analysis of integrated, hardware/software, ECLSS subsystem functionality and performance, supported by test. Test generated data used by the analysis shall include certification data from CO2 removal system components. Analysis shall also include generated data from ECLSS control software functional, performance, and interface testing.

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

V-HLS-S-HMTA-0019 Ventilation Rate

Statement: Analysis and Test. The capability to maintain a ventilation rate within the Integrated Lander shall be verified by analysis and test. The analysis shall include a review of the vehicle design, component certification data, and software control performance data. The analysis shall include a fluid dynamics model of the interior habitable volume and shall be of sufficient fidelity to identify potential areas within the

habitable volume with degraded air movement. The analysis shall include a plan to validate the model using data collected during the vehicle acceptance/qualification testing. The analysis shall consider the ventilation rate only at a single, nominal setting for all fan speeds and diffusers. The test shall be of the flight hardware's response to commands in the flight vehicle.

Verification Success Criteria: The verification shall be considered successful when the analysis and test establish that two-thirds (66.7%) of the atmosphere velocities are between 4.57m/min (15ft/min) and 36.58 m/min (120 ft/min) at a distance measured more than 0.15 m [6 inches]) from the vehicle walls during all mission phases except during toxic cabin events, or when the crew is not inhabiting the vehicle.

V-HLS-S-HMTA-0023 Comfort Zone

Statement: Analysis and Test. Maintaining the atmospheric temperature and relative humidity within the specified range shall be verified by analysis and test. The analysis shall include assessment of the Integrated Lander design via a thermal model of the habitable volume based on the final flight configuration as well as the pertinent aspects of the subsystems involved in controlling the habitable environment (such as ECLSS, TCS) as well as critical aspects of the external and internal environments that will impact the volume conditions (e.g. external heat loads, metabolic loads, etc.). The model shall be validated using relevant performance data (e.g. integrated testing, flight data, etc.). The test shall exercise and verify the correct response of the flight hardware and software commands.

Verification Success Criteria: The verification shall be considered successful when the analysis and test shows that the temperature can be maintained between 18 ºC (64.4 ºF) to 27 ºC (80.6 ºF) and the relative humidity between 25% and 75% during all nominal flight operations, excluding suited operations.

V-HLS-S-HMTA-0495 Thermal Comfort Capability

Statement: Analysis and Test. The capability of the occupied habitable volume to reach a temperature of 22.5°C during all mission phases shall be verified by analysis. Analysis shall be validated by relevant performance data (e.g. integrated testing, flight data, etc.). The test shall exercise and verify the correct response of the flight hardware and software commands.

Verification Success Criteria: The verification shall be considered successful when the analysis and test, using a moderate fidelity simulation of Integrated Lander environment and subsystems, shows that the temperature of occupied habitable volume can be adjusted to 22.5°C during worst-case mission thermal environments.

V-HLS-S-HMTA-0496 Temperature Selectability

Statement: Analysis and Test. The capability to provide and maintain selectable set points for habitable atmosphere temperature shall be verified by analysis, supported by test, of the crew interface and software and vehicle level thermal selectability.

Verification Success Criteria: The verification shall be considered successful when analysis, supported by test, shows that crew is provided the means to control the temperature in occupied habitable volume within steps no greater than 1°C and maintain that temperature at +/- 1°C.

V-HLS-S-HMTA-0497 Temperature Adjustability

Statement: Analysis and Test. The capability to adjust the temperature in the habitable volume by at least 1°C/hr shall be verified by analysis, supported by test, of the crew interface and software and vehicle level thermal adjustability.

Verification Success Criteria: The verification shall be considered successful when the analysis, supported by test shows that it takes no more than 1hr to adjust the temperature by 1°C after receiving the command.

V-HLS-S-HMTA-0025 Atmospheric Control

Statement: Analysis and Test. Capability for crew and remote operators to control atmospheric parameters and set-points for atmospheric pressure, O2 partial pressure, temperature, humidity, and ventilation shall be verified through analysis of integrated ECLSS subsystem (hardware and software) functionality and performance, supported by test. Test generated data used by the analysis shall include certification data from participating ECLSS subsystem components. Analysis shall also include generated data from ECLSS control software functional, performance, and interface testing.

Verification Success Criteria: The verification shall be considered successful when the analysis, supported by test, shows that each atmospheric parameter can be controlled by the crew and remote operators.

V-HLS-S-HMTA-0026 Atmospheric Data Recording

Statement: Analysis and Demonstration. Capability for each isolatable, habitable compartment to record pressure, humidity, temperature, ppO2, and ppCO2 data at the rates specified in Table C-1, Sampling Rates for Trending Environmental data shall be verified by analysis and demonstration. The analysis shall include a review of vehicle design supported by component certification data to show that the required sensors are located in the appropriate areas. A demonstration of the software with simulated sensor inputs shall show that the required values are properly recorded.

Verification Success Criteria: The verification shall be considered successful when the analysis and tests demonstrates that the Integrated Lander can automatically record pressure, humidity, temperature, ppO2, and ppCO2 data.

V-HLS-S-HMTA-0027 Atmospheric Data Displaying

Statement: Demonstration. Capability for the Integrated Lander to display real time values pressure, humidity, temperature, ppO2, and ppCO2 data from each isolatable, habitable compartment shall be verified by demonstration.

Verification Success Criteria: The demonstration shall be considered successful when the Integrated Lander displays to crew and remote operators the real time values for pressure, humidity, temperature, ppO2 and ppCO2 each isolatable, habitable compartment that are consistent with known or simulated values.

V-HLS-S-HMTA-0028 Atmospheric Monitoring and Alerting

Statement: Demonstration. Onboard monitoring of and alerts for atmospheric parameters shall be verified by demonstration. The demonstration shall use actual or simulated sensor data. Each atmospheric parameter shall be set at contingency levels to produce alerts.

Verification Success Criteria: The demonstration shall be considered successful when atmospheric parameters are monitored and alerts are provided to crew and remote operators when defined limits are reached for atmospheric parameters, including atmospheric pressure, humidity, temperature, ppO2, and ppCO2.

V-HLS-S-HMTA-0414 Volatile Organic Compound Monitoring and Alerting

Statement: Test. Volatile Organic Compound Monitoring and Alerting shall be verified by test.

Verification Success Criteria: Verification shall be considered successful when the test demonstrates that the Integrated Lander system provides the capability to monitor trace volatile organic compounds and demonstrates that the Integrated Lander system provides the capability to notify the crew and other mission systems whenever a monitored chemical parameter in the atmosphere approaches applicable limits in the pressurized habitable volume.

V-HLS-S-HMTA-0029 Smoke Particulate Monitoring and Alerting

Statement: Analysis and Demonstration. The ability of the Integrated Lander to detect combustion events and alert crew and other mission systems shall be verified by analysis and demonstration. An analysis shall be performed to identify the types and locations of potential ignition sources in areas with either forced air flow or credible oxygen enrichment/leakage and shall show that all such areas are covered by detection devices. This analysis shall consider the impacts of vehicle atmospheric pressure, oxygen concentration, and partial gravity on the detection and spread of fires. The demonstration shall show that the Integrated Lander notifies the crew and other mission systems when the smoke detectors are exposed to particle concentrations of the chosen threshold.

Verification Success Criteria: The verification shall be considered successful when the analysis shows all required areas have a combustion event detection capability and the demonstration shows that the Integrated Lander notifies the crew and other mission systems when particle concentrations exceed the chosen threshold.

V-HLS-S-HMTA-0029a Combustion Product Monitoring

Statement: Demonstration. The ability of the Integrated Lander to monitor toxic atmospheric components listed in TOX-VER-2016-03 shall be verified by demonstration. The demonstration shall show that the atmospheric monitoring instruments correctly and accurately measure the atmospheric concentration of toxic combustion products in the required ranges.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows a real time capability for the measurement and display of atmospheric concentrations of the specified toxic combustion products over the specified ranges with the required accuracy and resolution in TOX-VER-2016-03.

V-HLS-S-HMTA-0030 Toxic Release Monitoring and Alerting

Statement: Analysis and Demonstration. The requirement shall be verified by demonstration and analysis. An analysis shall be performed to identify fluids that may create a critical or catastrophic hazard if released into the habitable volume. The demonstration shall show that the detection system(s) automatically detect fluid leaks prior to the leaks creating a critical or catastrophic hazard and the Integrated Lander automatically detects the identified toxic releases and automatically notifies the crew and other mission systems when the monitoring system detects a release.

Verification Success Criteria: The verification is successful when the analysis and demonstration show the crew and other mission systems are automatically notified when a toxic release is automatically detected prior to the leak creating a critical or catastrophic hazard.

V-HLS-S-HMTA-0030a Contamination Monitoring

Statement: Analysis. The analysis shall include a review of Integrated Lander systems and operations to identify substances that could credibly be introduced into the habitable environment and result in a critical or catastrophic hazard. The analysis shall use data from qualification testing of the atmosphere monitoring systems and a review of the vehicle layout to show that concentration information is available to the crew and other mission systems during a contamination event. An analysis shall also be performed to determine the measurement response time required to support operational decisions. An analysis shall be performed to confirm that concentrations of gases and volatile liquids that could present a critical or catastrophic hazard is accurately computed and communicated to crew.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that the Integrated Lander can provide real-time monitoring across a relevant range of concentrations to crew and other mission systems to support appropriate operational response.

V-HLS-S-HMTA-0460 Protect Crew in Contaminated Atmosphere

Statement: Analysis and Test. The ability of the Integrated Lander to protect crew in a contaminated atmosphere shall be verified by analysis and test. The analysis shall identify credible toxic events and elapsed time for returning the habitable volume to levels below the 7-day SMAC. Further analysis shall show that the protective equipment will supply uncontaminated breathing gas to each crewmember for the longest duration of the credible toxic events. The HITL test shall measure time for test subjects to access and don flight-representative protective equipment and start flowing breathing gas. The test shall also show that the test subjects eyes and respiratory tract are protected after completion of donning. The number of test subjects shall be jointly agreed upon through the JTP.

Verification Success Criteria: Verification shall be considered successful when the analysis and test show the Integrated Lander provides protective equipment that is donnable in ≤15 seconds to protect the crews' eyes and respiratory tract while supplying uncontaminated breathing gas for the longest duration of credible toxic events.

V-HLS-S-HMTA-0460a Breathing Apparatus- Reduced Atmosphere

Statement: Analysis and Test. The ability of the Integrated Lander to provide breathing apparatus to support crew in a reduced atmosphere event shall be verified by analysis and test. The analysis shall identify credible events resulting in reduced cabin atmosphere, time to effect within which crew must have breathing apparatus support, and elapsed time for returning the crew to a safe environment. Further analysis shall show that the breathing apparatus will supply 100% O2 to each crewmember for the longest duration of the credible reduced atmosphere events. The HITL test shall measure time for test subjects to access and don flight-representative breathing apparatus and start flowing oxygen. The number of test subjects shall be jointly agreed upon through the JTP.

Verification Success Criteria: Verification shall be considered successful when the analysis and test show the Integrated Lander provides breathing apparatus that is donnable within time to effect and provides 100% O2 for the longest duration of credible reduced atmosphere events.

V-HLS-S-HMTA-0502 Contingency Cabin Leak Response

Statement: Analysis. The ability of the Integrated Lander to maintain required atmospheric conditions for a sufficient time shall be verified by analysis. A task analysis shall be performed to determine the amount of time required to establish the safe haven (e.g. by donning and leak-checking suits, gathering required equipment and supplies, isolating an airlock, etc.). The task analysis shall incorporate the results of HITL simulation testing where possible. A performance and consumables analysis shall show that the Integrated Lander is able to maintain required atmospheric conditions for the necessary amount of time in the presence of a 6.35 mm (¼ in) cabin hole. A mission timeline analysis shall be performed to determine the maximum length of time between the occurrence of a cabin leak and the opportunity for the Integrated Lander to dock

with a CSV in NRHO. A consumables and task analysis shall show that sufficient consumables exist to sustain the crew in the safe haven for the required amount of time, that required vehicle systems can operate with the Integrated Lander in safe haven configuration, and that the crew is able to perform the required functions (commanding, data monitoring, DCS treatment, etc.) from the safe haven.

Verification Success Criteria: Verification shall be considered successful when the analyses show the Integrated Lander has the ability to maintain the cabin atmosphere until the crew can establish a safe haven and that the safe haven can sustain the crew until they can dock and transfer to the CSV.

4.2.2 Cabin Contamination

V-HLS-S-HMTA-0041 Toxic Hazard Level Three

Statement: Analysis. Use of chemicals that are Toxic Hazard Level Three or below in the habitable volume of the Integrated Lander shall be verified by analysis. The analysis shall include a review of the materials and chemicals selected for spacecraft construction and their use in the operation of the vehicle.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that only Toxic Hazard Level Three or lower chemicals are used in the habitable volume of the vehicle and that no chemical decomposition products are a Toxicological Hazard Level Four.

V-HLS-S-HMTA-0042 Toxic Hazard Level Four

Statement: Analysis. Preventing Toxic Hazard Level Four chemicals from entering the habitable volume of the spacecraft shall be verified by analysis. The analysis shall include a review of the vehicle design and operational procedures to ensure that no credible failures (such as leaks or crew errors) could result in the release of Toxic Hazard Level Four compounds into the cabin.

Verification Success Criteria: The verification shall be considered successful when the analysis shows adequate controls are in place to prevent Toxic Hazard Level Four chemicals from entering the habitable volume of the spacecraft.

V-HLS-S-HMTA-0043 Chemical Decomposition

Statement: Inspection and Analysis. The prevention of chemical decomposition into hazardous compounds in the habitable volume shall be verified by analysis and inspection. The analysis shall identify chemicals that will be exposed to or have the potential to be introduced into the habitable volume and the likely chemical interactions with the environment. The inspection shall include a review of Program Safety Review Panel approval documentation.

Verification Success Criteria: The verification shall be considered successful when the analysis and inspection show that no chemicals have been used in the Integrated

Lander design that can be broken down or converted into compounds that threaten crew health and have the potential to be introduced into the habitable volume.

V-HLS-S-HMTA-0044 Atmosphere Contamination Limit – Inhabited Operations

Statement: Test and Analysis. The spacecraft's ability to control the concentration of gaseous pollutants in the habitable atmosphere shall be verified by analysis and test. The initial analysis shall evaluate the vehicle's active control of the concentration of individual trace chemical contaminants introduced into the cabin according to the load defined by Table 4-1: Trace Chemical Contaminant Design Load. The chemical contaminant load provided by Table 4-1 is a subset of the chemicals included in JSC 20584 and serves as the active trace contaminant control design basis until vehicle off-gassing test and vehicle system chemical release data become available. The vehicle off-gassing test shall be conducted according to SSP 41172, Section 5.2.4 and the resulting data shall be used to determine the integrated vehicle equipment off-gassing load for the contaminants observed by the test. The off-gassing load derived from the test supersedes the equipment off-gassing load component of Table 4-1: Trace Chemical Contaminant Design Load. Rates for chemicals released from system operations shall be quantified to supplement the equipment off-gassing and crew metabolic load components and shall be included in the final analysis.

Table 4-1: Trace Chemical Contaminant Design Load

Contaminant	GENERATION RATE	
	Off-Gassing (mg/d-kg)	Metabolic (mg/d-person)
Methanol	1.3×10^{-3}	4.9
Ethanol	3.7×10^{-2} C	10.7
n-butanol	1.0×10^{-3}	1.0
2-propanol	2.8×10^{-3}	4.5
Methanal (formaldehyde)	4.8×10^{-4}	0.7
Ethanal (acetaldehyde)	1.9×10^{-3}	2.8
Benzene	2.6×10^{-5}	1.3
Methylbenzene (toluene)	1.7×10^{-3}	1.2
Dimethylbenzenes (xylenes)	9.5×10^{-4}	3.9
Furan	1.9×10^{-6}	0.5
Dichloromethane	8.2×10^{-4}	0.2
2-propanone (acetone)	3.0×10^{-3}	22
Trimethylsilanol	3.1×10^{-3}	0
Hexamethylcyclotrisiloxane	7.1×10^{-3}	0
Ammonia	8.7×10^{-5}	51
Carbon monoxide	3.5×10^{-3}	18.4

Notes:

A) Off-gassing rate is for the mass of internal, non-structural equipment.
B) Off-gassing rates are superseded by rates derived from a vehicle off-gassing test when available.
C) For vehicles where ethanol-based housecleaning wipes will be used, an additional contribution of 1000 mg/day shall be added.
D) Internal system generation, vent, or leakage sources supplement this load as appropriate, e.g. systems with amine-containing components shall include a representative ammonia generation rate in addition to the equipment off-gassing and crew metabolic rates.

Verification Success Criteria: The verification shall be considered successful when the final analysis with test data incorporated shows the spacecraft can control the concentration of gaseous pollutants in the habitable atmosphere during all inhabited mission phases so that the toxic hazard index (T-value) is maintained below 1.0 unit based on 180-day (SMACs).

V-HLS-S-HMTA-0482 Flammable Constituents Limit

Statement: Analysis and Test. The limit of flammable constituents shall be verified by test and analysis. Component testing of the gas control system(s) shall be performed to establish removal rates for hydrogen and methane. An analysis using these removal rates and the generation rates from RQMT-006, Table C-4: Flammable Contaminant Design Load shall show that the concentrations of hydrogen and methane stay below the limits in RQMT-006, Table C-3: Flammable Chemical Contaminant Limits for the extent of the mission.

Verification Success Criteria: The verification shall be considered successful when component testing of the vehicle's gas removal system(s) and vehicle-level analysis using generation rates from RQMT-006, Table C-4: Flammable Contaminant Design Load shows that flammable gases are controlled as specified over the duration of the mission in both ventilated and non-ventilated areas.

V-HLS-S-HMTA-0503 Post Contamination Atmosphere Levels

Statement: Analysis. The Integrated Lander ability to return the habitable atmosphere to levels below the 7-day SMAC shall be verified by analysis. Hazard analysis shall identify credible contamination events and the resulting chemical contaminants and their concentrations. Further analysis shall evaluate the vehicle's active control of the concentration of contaminants released into the habitable atmosphere after defined contamination events.

Verification Success Criteria: The verification shall be considered successful when the analysis shows the Integrated Lander can return the habitable atmosphere to levels below the 7-day SMACs, contained in JSC 20584, within 24 hours.

V-HLS-S-HMTA-0046 Particulate Matter

Statement: Analysis. The ability of the Integrated Lander to limit the amount of particulate matter in the habitable volume shall be verified by analysis. The analysis shall include a review of the vehicle design to ensure that there is adequate airflow and filtration to control particulate matter in the habitable volume. The analysis shall use the provided generation rates to account for the particulate generation from the onboard crew.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that the Integrated Lander controls total dust to <3 mg/m^3, and the respirable fraction of the total dust <2.5 µm in aerodynamic diameter to <1 mg/m^3.

V-HLS-S-HMTA-0047 Lunar Dust Contamination

Statement: Analysis and Test. The control of lunar dust in the internal atmosphere shall be verified by integrated system analysis supported by test. The analysis shall include a review of the vehicle design and results from testing components of the Atmosphere Revitalization System (ARS).

Verification Success Criteria: The verification shall be considered successful when the analysis supported by test shows that the system limits lunar dust in the habitable volume for particles 0.02 to 10 μm in size below a time-weighted average of 0.4 mg/m^3 during daily exposure periods that may persist over a 30-day mission.

V-HLS-S-HMTA-0480 Lunar Dust Monitoring

Statement: Test. The ability of the system to monitor, record, and transmit the atmospheric concentration of lunar dust in the habitable volume shall be verified by test. The test shall show that the atmospheric monitoring instruments correctly and accurately measure the atmospheric concentration of lunar dust in the required ranges.

Verification Success Criteria: Verification shall be considered successful when the test shows that the Integrated Lander provides the capability to monitor, record, and transmit, to the crew and other mission systems, the atmospheric concentration of lunar dust in the habitable volume.

V-HLS-S-HMTA-0050 Condensation Limitation

Statement: Analysis. The condensation persistence on surfaces shall be verified by thermal analysis to predict internal surface temperatures that may result in condensation plus assessment of expected water on internal surfaces.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that condensation persistence is limited to 1 hour a day on surfaces within the internal volume during the mission.

V-HLS-S-HMTA-0051 Microbial Air Contamination

Statement: Analysis. The limitation of microbial contaminants in the internal atmosphere shall be verified by analysis. The analysis shall include a review of the vehicle design to ensure adequate airflow and filtration is in place.

Verification Success Criteria: The verification shall be considered successful when the analysis shows continuous air flow within the vehicle that has been cleaned to have at least 99.97% of airborne particles 0.3 micrometers (μm) and larger in diameter/size removed.

V-HLS-S-HMTA-0432 Atmospheric Contamination Limit –Ingress

Statement: Test and Analysis. The ability to limit accumulation of gaseous pollutants in the Integrated Lander prior to crew first entry on-orbit or reingress from uninhabited

operations shall be verified by test and analysis. A pre-flight test shall be used to determine the integrated material off-gassing load and off-gassing rate in the Integrated Lander using a NASA-approved lab and approach. The analysis shall evaluate the sizing and performance of the active trace contaminant control system using data from the off-gassing test and system chemical release data.

Verification Success Criteria: The verification of gaseous pollutant control in the Integrated Lander prior to crew first entry on-orbit shall be considered successful when the analysis shows the predicted total T value is less than 1.0 T units based on 180-day SMACs for the combined load of material off-gassing and system chemicals.

V-HLS-S-HMTA-0433 Pre-Flight Surface Microbial Contamination

Statement: Test. This requirement shall be verified by test. Microbiological samples from the Integrated Lander vehicle surfaces shall be collected prior to cargo integration for each flight and as close to hatch closure as practical (20 to 30 days prior to launch if possible). Analyses of the microbial samples shall be performed to verify that Integrated Lander vehicle meets the requirement as specified by NASA or a NASA approved laboratory.

Verification Success Criteria: The verification shall be considered successful when the test show microbial levels are within the specified bacterial and fungal parameters and no medically significant organisms have been isolated.

HLS-S-HMTA-0510 Pre-Flight Air Microbial Contamination

Statement: Test. The pre-flight air microbial contamination shall be verified by test. Microbiological samples from the Integrated Lander vehicle atmosphere shall be collected as close to hatch closure as practical (20 to 30 days prior to launch if possible) for each flight. Analyses of the microbial sample test data shall be performed to verify that Integrated Lander vehicle meets the requirement as specified by NASA or a NASA approved laboratory.

Verification Success Criteria: The verification shall be considered successful when the analyses of the test data show microbial levels are within the specified bacterial and fungal parameters, and no medically significant organisms have been identified.

V-HLS-S-HMTA-0481 In-Flight Sampling of Water, Cabin Air, and Surfaces

Statement: Inspection. The capability for in-flight sampling, analysis, and reporting of select constituents shall be verified by inspection.

Verification Success Criteria: The verification shall be considered successful when the inspection shows that the Integrated Lander provides capabilities for in-flight sampling, analysis and reporting of select constituents in water, cabin air, and cabin surfaces.

4.2.3 Cabin Pressure

V-HLS-S-HMTA-0020 Total Pressure Tolerance Range for Indefinite Crew Exposure

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

Verification Success Criteria: The verification shall be considered successful when the test and analysis data show that the vehicle can maintain pressure of the internal atmosphere within the limits specified in NASA/SP-2010-3407, Human Integration Design Handbook (HIDH) Table 6.2-3 Physiological Total Pressure Limits for Crew Exposure.

V-HLS-S-HMTA-0021 Rate of Pressure Change

Statement: Analysis and Test. The rate of total pressure change shall be verified through analysis of integrated, hardware/software, ECLSS subsystem functionality and performance, supported by test. Test data used by the analysis shall include data generated during a worst-case scenario for pressure change during nominal operations.

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

V-HLS-S-HMTA-0431 Vehicle Pressure Control

Statement: Analysis and Test. The vehicle capability to pause within 1psia from when the decision is made to pause and to increase or decrease pressure after pausing shall be verified through analysis of integrated, hardware/software, ECLSS subsystem functionality and performance, supported by test. Test generated data used by the analysis shall include participating ECLSS system component certification data. Analysis shall also include generated data from ECLSS control software functional, performance/latency, and interface testing.

Verification Success Criteria: The verification shall be considered successful when the test and analysis shows that the crew is able to pause the vehicle pressure change within 6.89 kPa (1 psia) from when the crewmember decides to pause, and the crewmember is subsequently able to increase or decrease pressure.

V-HLS-S-HMTA-0031 Decompression Sickness (DCS) Risk Mitigation for EVA Preparation

Statement: Test. Maintaining the internal pressure and gaseous oxygen concentration for the required time durations for de-nitrogenation shall be verified by test. The test

shall adjust the pressures and concentrations as defined in NASA-validated pre-breath protocol.

Verification Success Criteria: The Verification shall be considered successful when the test shows that the vehicle can vary pressures and gas concentrations per the de-nitrogenation protocol.

V-HLS-S-HMTA-0032 Decompression Sickness Treatment Capability
Statement: Analysis and Test. The ability of the airlock to pressurize to a minimum pressure for DCS treatment shall be verified by analysis. The analysis shall show that the system can apply pressure within the timeframes required, maintain the atmospheric pressure within the specified range, and that adequate consumables (O2, power) are available to complete the treatment. Subsystem component qualification testing shall verify hardware performance and software testing shall verify software control of pressure within required range.

Verification Success Criteria: The verification shall be considered successful when the test results show that the system can pressurize to required levels within the required time frame and sufficient oxygen consumables are allotted for treatment and subsystem component level testing shows that the Integrated Lander can maintain the performance required to achieve these pressures.

V-HLS-S-HMTA-0494 Protect Crew in Compromised Habitable Atmosphere
Statement: Analysis. Ability to support crew for an extended period of time shall be verified by analysis of consumables provided to bridge crew from point of failure to a safe environment or another system which will support human life.

Verification Success Criteria: Verification shall be considered successful when analysis shows the spacesuit/safe haven system can preserve crew life and performance for all recoverable failures to an operationally relevant endpoint.

4.2.4 Acceleration and Vibration Limits

V-HLS-S-HMTA-0059 Sustained Translational Acceleration Limits
Statement: Analysis and Test. The crew exposure to sustained linear acceleration shall be verified by analysis that is supported by test. Analysis shall use a certified simulation to identify all flight phase scenarios, as well as Monte Carlo studies with dispersed Guidance, Navigation, and Control (GN&C), vehicle and environmental factors as appropriate. Tests shall be used to validate the model using data obtained from nominal flight tests, and/or other available flight and ground-based tests. The test data shall provide continuous acceleration measures in order to compute the total linear acceleration that would be experienced by the crew directly by translational and gravitational acceleration, and indirectly by off-axis rotation (i.e., centrifugal force). Such testing will require on-board acquisition (or sampling) of 3D linear and 3D rotational acceleration (along and around the x, y, and z axes) on a millisecond timescale.

Verification Success Criteria: The verification shall be considered successful when the analyses indicate with acceptable confidence and acceptable consumer risk that linear acceleration, accumulated for durations of 500 ms or more, are no greater than the limits depicted in HLS-RQMT-006, Figure C-2: +GX Linear Sustained Acceleration Limits, HLS-RQMT-006, Figure C-3: -GX Linear Sustained Acceleration Limits, HLS-RQMT-006, Figure C-4: ±GY Linear Sustained Acceleration Limits, HLS-RQMT-006, Figure C-5: +GZ Linear Sustained Acceleration Limits, and HLS-RQMT-006, and Table C-5: $-G_z$ Linear Sustained Acceleration Limits per coordinate frame shown in Figure C-6: Acceleration Environment Coordinate System.

V-HLS-S-HMTA-0060 Rotational Velocity

Statement: Analysis and Test. The crew exposure to rotational velocities shall be verified by analysis that is supported by test. The test shall consist of flight tests. Nominal flight tests shall provide acceleration measurements to evaluate vehicle rotational velocity. Testing will require continuous on-board acquisition (or sampling) of 3D rotational velocity at an acceptable sampling rate. The analysis shall use a certified simulation to verify all nominal flight phase scenarios, as well as Monte Carlo studies with dispersed Guidance, Navigation, and Control (GN&C), and vehicle and environmental factors.

Verification Success Criteria: The verification shall be considered successful when the analyses indicate with acceptable confidence and acceptable consumer risk that the rotational velocities, accumulated for durations of 500 ms or more, are no greater than the limits depicted in HLS-RQMT-006, Figure C-7: Rotational Velocity Limits.

V-HLS-S-HMTA-0061 Sustained Rotational Acceleration Due to Cross-Coupled Rotation

Statement: Analysis and Test. The crew exposure to sustained rotational acceleration caused by cross-coupled rotations shall be verified by analysis that is supported by test. The analysis shall use a certified simulation to verify all nominal flight phase scenarios. The simulation shall use rotational velocity measurements collected from flight tests in order to evaluate vehicle angular acceleration caused by cross-coupled rotation. Testing shall require continuous on-board acquisition (or sampling) of 3D rotational velocities in an orthogonal coordinate frame at an acceptable rate. Rotational velocities shall be decomposed into their orthogonal principal components before computing accelerations due to their respective cross-product velocity terms. The analysis shall use a certified simulation to verify all nominal flight phase scenarios, as well as Monte Carlo studies with dispersed Guidance, Navigation, and Control (GN&C), and vehicle and environmental factors.

Verification Success Criteria: The verification shall be considered successful when the analysis indicates with acceptable confidence and acceptable consumer risk that the sustained rotational acceleration in any of the velocity principal-component axes is no greater than 2 rad/s2.

V-HLS-S-HMTA-0062 Transient Translational Acceleration

Statement: Analysis and Test. The risk of injury to crewmembers caused by accelerations during dynamic mission phases shall be verified by analysis supported by test. Analysis shall use a certified simulation to identify all flight phase scenarios, as well as bounding Monte Carlo studies with dispersed GN&C, vehicle and environmental factors, as appropriate, to determine likelihood of occurrence. Tests shall be used to validate the model using data obtained from nominal flight tests, and/or other available flight and ground-based tests.

Verification Success Criteria: The verification shall be considered successful when the analysis indicates with acceptable confidence with acceptable consumer risk that the vehicle meets the limits specified in NASA/TM-20205008198, Table 2 “Updated Dynamic Response Limits for Standing.”

V-HLS-S-HMTA-0065 Vehicle Acceleration Monitoring and Analysis

Statement: Analysis and Demonstration. Vehicle Acceleration Monitoring and Analysis shall be verified by demonstration and analysis.

Verification Success Criteria: The verification shall be considered successful when demonstration shows that: a) HD video cameras are in place to capture the kinematic responses of all crewmembers, b) transducers are mounted in the appropriate places to capture the 6 DOF accelerations (i.e., translation and rotation) of all crewmembers during dynamic phases of flight, and c) vehicle accelerations are measured. Analysis shall show that an end-to-end collection of the HD video data is captured at a rate of at least 120 frames per second, and crew 6 DOF acceleration data is recorded accurately at a rate of at least 1000 samples per second. The analysis shall show that the video and acceleration data are synchronized so that the data can be temporally correlated.

V-HLS-S-HMTA-0084 Vibration Exposures during Dynamic Phases of Flight

Statement: Analysis and Test. The dynamic phases of flight vibration exposure health limit shall be verified by analysis supported by test. The analysis shall consist of a simulation of the vibration levels at the crew seat and/or other body supporting surfaces, assuming that the seat and/or other supporting surfaces are relatively rigid structures. The weighted acceleration shall be calculated in accordance with ISO 2631-1:1997(E), using the frequency weighting Wd for the body X and Y directions, Wk for the Z direction, and a multiplying factor k=1.4 in the X and Y directions and k=1 in the Z direction (ISO 2631-1:1997(E), Tables 1 and 3 and Figure 1, and Section 7.2). Test data obtained from ground vibration testing and/or flight tests shall be used to support validation of the model and to evaluate vehicle vibration under all dynamic phases of flight. Testing and analysis will require measurement and simulation of translational acceleration along the three orthogonal axes, X, Y, and Z of the seat and/or other body supporting surfaces, at an acceptable sampling rate to determine the vibration profile.

The vibration levels that reach the crew are the result of several factors provided by the launch vehicle, the crew vehicle, connecting structure, means of vibration attenuation, etc. For cases where the crew is suited, the spacesuit needs to be considered as an integral part of the connecting structure. The resultant vibration levels will likely be too complex to be determined from analysis alone. In order to determine if the vehicle has met the vibration limit, which is a matter of crew safety, actual vehicle test data are required to understand what the crew will experience and to provide data for additional analyses. The measurement of acceleration is to be made at the crew seat and/or other body supporting surfaces and assumes these surfaces are relatively rigid. ISO 2631-1:1997(E) calls for the measurement of acceleration at the supporting surfaces between a seat and the occupant to account for the effects of any resilient cushion material. The measurement is being made on the rigid seat (couch) structure with respect to the body's X, Y, and Z coordinates defined in ISO 2631-1:1997(E). It is assumed that the occupant will be rigidly coupled to the supporting surfaces by the restraint system, minimizing any amplification of vibration.

Verification Success Criteria: The verification shall be successful when the analyses indicate with acceptable confidence and acceptable consumer risk that the vectorial sum of the X, Y, and Z frequency-weighted accelerations between 0.5 and 80 Hz at the crew interface to the seat and/or other supporting surfaces do not exceed the levels and exposure durations in HLS-RQMT-006, Table C-6: Frequency-Weighted Vibration Limits by Exposure Time during Dynamic Phases of Flight.

V-HLS-S-HMTA-0085 Long-Duration Vibration Exposure Limits for Health during Non-Sleep Phases of Mission

Statement: Analysis and Test. Long-Duration Vibration Exposure Limits for Health during Non-Sleep Phases of Mission shall be verified by analysis supported by test. The analysis shall consist of a simulation of the vibration levels at the crew seat and/or other body supporting surfaces, assuming that the seat and/or other supporting surfaces are relatively rigid structures. The weighted acceleration shall be calculated in accordance with ISO 2631-1:1997, using the frequency weighting Wd for the body X and Y directions, Wk for the Z direction, and a multiplying factor k=1.4 in the X and Y directions and k=1 in the Z direction (ISO 2631-1:1997, Tables 1 and 3 and Figure 1, and Section 7.2). Test data obtained from ground vibration testing and/or flight tests shall be used to support validation of the model and to evaluate vehicle vibration under all phases of flight. Testing and analysis will require measurement and simulation of translational acceleration along the three orthogonal axes, X, Y, and Z of the seat and/or other body supporting surfaces, at an acceptable sampling rate to determine the vibration profile.

The vibration levels that reach the crew are the result of several factors provided by the launch vehicle, the crew vehicle, connecting structure, means of vibration attenuation, etc. For cases where the crew is suited, the spacesuit needs to be considered as an integral part of the connecting structure. The resultant vibration levels will likely be too complex to be determined from analysis alone. In order to determine if the vehicle has met the vibration limit, actual vehicle test data are required to understand what the crew

will experience and to provide data for additional analyses. The measurement of acceleration is to be made at the crew seat and/or other body supporting surfaces and assumes these surfaces are relatively rigid. ISO 2631-1:1997 calls for the measurement of acceleration at the supporting surfaces between a seat and the occupant to account for the effects of any resilient cushion material. The measurement is being made on the rigid seat (couch) structure with respect to the body's X, Y, and Z coordinates defined in ISO 2631-1:1997 Figure 1. It is assumed that the occupant will be rigidly coupled to the supporting surfaces by the restraint system, minimizing any amplification of vibration.

Verification Success Criteria: The verification shall be successful when the analyses indicate with acceptable confidence and acceptable consumer risk that the vectorial sum of the X, Y, and Z frequency-weighted accelerations between 0.5 and 80 Hz at the crew interface to the seat and/or other supporting surfaces does not exceed the limits in HLS-RQMT-006, Figure C-8: Long-Duration Vibration Exposure Limits for Health during Non-Sleep Phases of Mission.

V-HLS-S-HMTA-0087 Vibration Limits for Performance

Statement: Analysis and Test. Vibration Exposure Limits for Crew Performance shall be verified by analysis supported by test. The analysis shall consist of a simulation of the vibration levels at the crew seat and/or other body supporting surfaces, assuming that the seat and/or other supporting surfaces are relatively rigid structures. The weighted acceleration shall be calculated in accordance with ISO 2631-1:1997, using the frequency weighting Wd for the body X and Y directions, Wk for the Z direction, and a multiplying factor k=1.4 in the X, Y and Z directions (ISO 2631-1:1997, Tables 1 and 3 and Figure 1, and Section 7.2). Test data obtained from ground vibration testing and/or flight tests shall be used to support validation of the model and to evaluate vehicle vibration under all phases of flight. Testing and analysis will require measurement and simulation of translational acceleration along the three orthogonal axes, X, Y, and Z of the seat and/or other body supporting surfaces, at an acceptable sampling rate to determine the vibration profile.

The vibration levels that reach the crew are the result of several factors provided by the launch vehicle, the crew vehicle, connecting structure, means of vibration attenuation, etc. For cases where the crew is suited, the spacesuit needs to be considered as an integral part of the connecting structure. The resultant vibration levels will likely be too complex to be determined from analysis alone. In order to determine if the vehicle has met the vibration limit, actual vehicle test data are required to understand what the crew will experience and to provide data for additional analyses. The measurement of acceleration is to be made at the crew seat and/or other body supporting surfaces and assumes these surfaces are relatively rigid. ISO 2631-1:1997 calls for the measurement of acceleration at the supporting surfaces between a seat and the occupant to account for the effects of any resilient cushion material. The measurement is being made on the rigid seat (couch) structure with respect to the body's X, Y, and Z coordinates defined in ISO 2631-1:1997 Figure 1. It is assumed that the occupant will be rigidly coupled to

the supporting surfaces by the restraint system, minimizing any amplification of vibration.

Verification Success Criteria: The verification shall be successful when the analyses indicate with acceptable confidence and acceptable consumer risk that the vectorial sum of the X, Y, and Z frequency-weighted accelerations between 0.5 and 80 Hz at the crew interface to the seat and/or other supporting surfaces does not exceed the accumulated daily exposure for the durations listed in HLS-RQMT-006, Table C-7: Frequency-Weighted Vibration Limits by Accumulated Exposure Duration for Periods Requiring Crew Task Performance.

4.2.5 Acoustic Noise Limits

V-HLS-S-HMTA-0068 Intermittent Noise Limits

Statement: Analysis and Test. The intermittent noise shall be verified by test and analysis. Sound Pressure Level (SPL) measurements shall be made of the actual flight hardware (each serialized unit) in its flight configuration with closeouts installed. Hardware shall be operated across the expected range of settings, including settings corresponding to the expected highest noise levels. Measurements shall be made using a Type 1 integrating-averaging sound level meter for each item that operates (produces noise) intermittently. The maximum A-weighted overall SPL (LAmax) shall be measured with a fast (125 ms) exponentially-weighted time-averaged response. Analysis shall be used to include any measured acoustical effects of the hardware installation configuration or to combine measured sound pressure levels of hardware items that must be operated simultaneously when these factors are not accurately represented in field tests. If the noise generated by a specific hardware item is influenced by the operation of another hardware item, then these hardware items shall be tested together. Analysis shall also be used to calculate the maximum operational duration to include the total time during any 24-hour period that the hardware item operates above the continuous noise limits given in HLS-S-HMTA-0076 in HLS-RQMT-006, Table C-11: Octave Band SPL Limits for Continuous Noise.

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. However, during suited operation, the noise reduction provided by the spacesuit can be taken into account in the analysis to satisfy this requirement. Intermediate testing and analysis should be performed and reviewed by NASA to ensure confidence that compliance with this requirement will be met and to preclude late impacts to cost, schedule, and hardware. Prototype or qualification units should be tested prior to manufacture of the actual flight equipment.

Verification Success Criteria: This verification shall be considered successful when the test (and any performed simulations) indicates that the maximum noise level for the

duration of intermittent operation, measured 0.6 m from the loudest point on the hardware surface or at the center of the vehicle if the noise source is external to the vehicle, meets the level and duration limits specified in HLS-S-HMTA-0068 in HLS-RQMT-006, Table C-10: Intermittent Noise A-Weighted SPL and Corresponding Operational Duration Limits for any 24-Hour Period (measured at 0.6-m distance from the source).

V-HLS-S-HMTA-0069 Cabin Depressurization Valve Hazardous Noise Limit

Statement: Analysis and Test. The cabin depressurization valve hazardous noise limit shall be verified by test and analysis. The test and analysis shall consist of estimating the maximum sound level at the crewmember's ear by combining significant noise sources from estimates of valve noise and including acoustic insertion losses of protective devices. The pressure-relief valve noise shall be determined by test. If allowed, the effectiveness of hearing protection, headsets, and helmets shall be determined by test.

Verification Success Criteria: The verification shall be considered successful when tests and analysis indicate that, during pressure relief valve operations, the maximum level predicted at the crewmember's ears is 105 dBA or less.

V-HLS-S-HMTA-0070 Cabin Depressurization Valve Noise Dose Limits

Statement: Analysis and Test. The cabin depressurization valve - noise dose limit shall be verified by test and analysis. The test and analysis shall consist of estimating the noise level as a function of time at the crewmember's ear by combining significant noise sources from estimates of valve noise and including acoustic insertion losses of protective devices. The pressure-relief valve noise shall be determined by test. If allowed, the effectiveness of hearing protection, headsets, and helmets shall be determined by test. Noise levels for the balance of the 24-hour calculation period shall be assumed to be 65 dBA.

Verification Success Criteria: The verification shall be considered successful when the analysis and test indicate the cabin depressurization valve noise, predicted at the crewmember's ear over 24-hour period, is 100% or less.

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

Statement: Analysis and Test. The noise dose limits for lunar landing and ascent shall be verified by test and analysis. The noise level as a function of time for lunar landing and ascent measured at the crewmember’s ears shall be determined by flight-testing. The test and analysis shall consist of estimating the noise level as a function of time at the crewmember’s ear by combining significant noise sources from estimates of rocket noise and other relevant sources, and including acoustic insertion losses of acoustic isolation and protective devices. The rocket noise should be determined by test. Acoustic insertion losses of the pressure shell and other materials shall be determined by test. The effectiveness of hearing protection, headsets, and helmets shall be

determined by test. Noise levels for the balance of the 24-hour calculation period shall be assumed to be 65 dBA.

Verification Success Criteria: The verification shall be considered successful when tests and analysis indicate that the 24-hour noise dose associated with ascent, landing, and ascent abort predicted at the crewmember's ears is 100% or less.

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

Statement: Analysis and Test. The hazardous noise limit for ascent and landing shall be verified by test and analysis. The maximum noise level measured at the crewmember's ears shall be determined by flight-testing. The test and analysis shall consist of estimating the maximum sound level at the crewmember's ear by combining significant noise sources from estimates of rocket noise and external flow boundary layer noise and including acoustic insertion losses of acoustic isolation and protective devices. The rocket noise should be determined by test. Acoustic insertion losses of the pressure shell and other materials shall be determined by test. The effectiveness of hearing protection, headsets, and helmets shall be determined by test.

Verification Success Criteria: The verification shall be considered successful when the tests and analysis indicate that the maximum level predicted at the crewmember's ears is 105 dBA or less during ascent and landing.

V-HLS-S-HMTA-0073 Sound Level Ceiling Limit for Aborts

Statement: Analysis and Test. The hazardous noise limit during abort shall be verified by test and analysis. The maximum noise level measured at the crewmember's ears shall be determined by flight-testing. The test and analysis shall consist of estimating the maximum sound level at the crewmember's ear by combining significant noise sources from estimates of rocket noise and other relevant sources and including acoustic insertion losses of acoustic isolation and protective devices. The rocket noise should be determined by test. Acoustic insertion losses of the pressure shell and other materials shall be determined by test. The effectiveness of hearing protection, headsets, and helmets shall be determined by test.

Verification Success Criteria: The verification shall be considered successful when the tests and analysis indicate that the maximum level predicted at the crewmember's ears is 115 dBA or less during launch abort.

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

Statement: Analysis and Test. The impulse noise limit for ascent and landing shall be verified by test and analysis. The impulse noise level measured at the crewmember's ears shall be determined by flight-testing. The test and analysis shall consist of estimating the impulse noise level at the crewmember's ear by combining significant noise sources and including acoustic insertion losses of acoustic isolation and protective devices. The ignition noise should be determined by test. Acoustic insertion losses of the pressure shell and other materials shall be determined by test. The

effectiveness of hearing protection, headsets, and helmets shall be determined by test. Peak-hold sound pressure level measurements shall be made using a Type 1 sound level meter. The frequency response of the sound level meter shall extend to at least 6 Hz at its lower limit. Formal verification is not required for equipment with impulse noises that have peak overall SPLs of less than 110 dB.

Verification Success Criteria: The verification shall be considered successful when the test and analysis results indicate that the peak overall sound pressure level predicted at the crewmember's ears is less than 140 dB.

V-HLS-S-HMTA-0075 Hazardous Noise Limits for All Phases except Ascent, Landing and Abort and Other Lander Burns

Statement: Analysis and Test. The hazardous noise limit shall be verified by test and analysis. The SPL measurements for this verification shall be made using the actual flight equipment (each serialized unit) including GFP, 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. 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.

Verification Success Criteria: The verification shall be considered successful when field testing (and any performed simulations) indicates that the maximum level, measured at any location (no closer than 8 cm to surfaces) within the habitable volume and at any maintenance operation head location, is below 85 dBA (LAmax) for communications and 95 dBA for alarms for any combination of individual hardware items that may occur simultaneously.

V-HLS-S-HMTA-0076 Continuous Noise Limits

Statement: Test. The continuous noise limit shall be verified by test. The measurements shall be made within the vehicle in the flight configuration with integrated GFP, 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). Lower nominal settings of major hardware components shall also be tested and documented because expected maximum operational settings may not correspond to the highest noise levels. Noise attenuation gained by the use of hearing protection is not to be considered toward the compliance of this requirement because hearing protection may not always be worn. Intermediate testing and analysis should be performed and reviewed by NASA to ensure confidence that compliance with this requirement will be met and to preclude late impacts to cost, schedule, and hardware.

Verification Success Criteria: The verification shall be considered successful when field testing indicates that:
a) the measured Leq at each expected work and sleep station head location and the estimated center of the habitable volume do not exceed the levels within each octave band indicated in HLS-RQMT-006, Table C-11: Octave Band SPL Limits for Continuous Noise,
b) the spatially-averaged SPLs (average of pressure-squared values) throughout the habitable volume do not exceed the levels given in HLS-RQMT-006, Table C-11: Octave Band SPL Limits for Continuous Noise. The spatial average shall include locations used in 1) above, and a sufficient number of additional locations, to achieve a ± 2 dB 90% confidence interval within each octave band from 250 Hz to 16 kHz, and
c) no octave band sound pressure level measured at any location or at the maximum level location (i.e., the location of the maximum A-weighted overall sound pressure level found with a handheld sound level meter) within the entire habitable volume is more than 4 dB above the levels specified in HLS-RQMT-006, Table C-11: Octave Band SPL Limits for Continuous Noise at the corresponding octave- band center frequency.

V-HLS-S-HMTA-0077 Alarm Maximum Sound Level Limit
Statement: Test. The maximum alarm SPL shall be verified by test. The SPL measurements for this verification shall be made using the actual flight equipment (each serialized unit), installed in the actual flight vehicle in its final configuration with all closeouts installed. SPL measurements shall be made using a Type 1 integrating-averaging sound level meter. The maximum A-weighted SPL (LAmax) with a fast (125 ms) exponentially weighted time averaged response shall be measured. Serialized units must be verified individually because of reverberation effects inside the vehicle. Noise attenuation gained by the use of hearing protection is not to be considered toward the compliance of this requirement because hearing protection may not always be worn.

Intermediate testing and analysis should be performed and reviewed by NASA to ensure confidence that compliance with this requirement will be met and to preclude late impacts to cost, schedule, and hardware.

Verification Success Criteria: The verification shall be considered successful when field-testing indicates that the maximum level, measured at any location (no closer than 8 cm to surfaces) within the habitable volume is below 95 dBA for alarms.

V-HLS-S-HMTA-0078 Annoyance Noise Limits for Crew Sleep

Statement: Test. The annoyance noise limit shall be verified by test. The measurements shall be made within the vehicle in the flight configuration with integrated GFP, portable equipment, payloads, and cargo installed. Hardware shall be operated at settings that occur during crew rest periods. Measurements shall be made at expected head locations during sleep using a Type 1 integrating-averaging sound level meter. Measurement locations shall be no closer than 8 cm from any surface. Peak-hold sound pressure level (impulse noise) and A-weighted Overall SPL measurements shall be made. Intermediate testing and analysis should be performed and reviewed by NASA to ensure confidence that compliance with this requirement will be met and to preclude late impacts to cost, schedule, and hardware.

Verification Success Criteria: The verification shall be considered successful when measurements show that the peak overall sound pressure levels are less than 10 dB and 10 dBA, respectively, above the peak overall sound pressure level and A-weighted overall sound pressure level of the applicable continuous noise requirement during crew sleep periods.

V-HLS-S-HMTA-0079 Impulse Noise Limit

Statement: Test. The impulse noise limit shall be verified by test. The SPL measurements for this verification shall be made using the actual flight equipment (each serialized unit). Formal verification is not required for equipment with impulse noises that have peak overall SPLs of less than 110 dB. Peak-hold sound pressure level measurements shall be made using a Type 1 sound level meter on all equipment that emits significant impulse noise at expected head locations. The frequency response of the sound level meter shall extend to at least 6 Hz at its lower limit.

Measurement locations relative to specific noise sources must correspond to the shortest distance from the loudest point on the hardware to the closest possible crew member head location. 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.

Verification Success Criteria: This verification shall be considered successful when the test results show that the peak overall sound pressure level measurements are less than 140 dB.

V-HLS-S-HMTA-0080 Narrow-Band Noise Limits

Statement: Test. The tonal and narrow-band noise limit shall be verified by test. The measurements shall be made within the vehicle in the flight configuration with integrated GFP, 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 frequency from HLS-RQMT-006, Table C-11: Octave Band SPL Limits for Continuous Noise using a Type 1 integrating-averaging sound level meter with a 20-second averaging time. Tonal and narrow-band component measurements shall also be made using a Fast Fourier Transform (FFT) with a frequency resolution of 1 Hz. Measurements shall be made at expected work and head locations during sleep.

Verification Success Criteria: The verification shall be considered successful when the test indicates that the maximum levels of tones and narrow band components, measured at all work and head locations during sleep, is at least 10 dB less than the values in the HLS-S-HMTA-0076 in HLS-RQMT-006, Table C-11: Octave Band SPL Limits for Continuous Noise of the octave band that contains the component or tone.

V-HLS-S-HMTA-0081 Infrasonic Sound Pressure Limits

Statement: Analysis and Test. The Ascent and Landing Phases - Infrasonic Noise Limit shall be verified by test and analysis. The maximum noise level measured at the crewmember’s ears shall be determined by flight-testing. The test and analysis shall consist of estimating the maximum sound level at the crewmember’s ear by combining significant noise sources from estimates of rocket noise and external flow boundary layer noise and including acoustic insertion losses of acoustic isolation and protective devices. The rocket noise should be determined by test. Acoustic insertion losses of the pressure shell and other materials shall be determined by test. The effectiveness of hearing protection, headsets, and helmets is not allowed for this verification. Sound pressure measurements shall be made over a frequency range from 1 to 20 Hz, using a Type 1 integrating-averaging sound level meter at expected work-station head locations. The infrasonic noise level shall be measured via a 20 second Leq (slow time weighting).

Verification Success Criteria: Rocket and aerodynamic sources present during ascent, landing, abort, or other long duration rocket firings are considered to be the only credible noise sources for this requirement. The verification shall be considered successful when the test and analysis indicate that the unweighted overall sound pressure level is 150 dB or less, at each expected work-station head-location.

V-HLS-S-HMTA-0082 Noise Limit for Personal Communication Devices

Statement: Test. The personal communication device SPL limit shall be verified by test. Measurements shall be made using an IEC 60318-4 compliant acoustic test fixture or head and torso simulator. Testing shall be conducted to evaluate the upper limits of personal audio devices across all operable 1/3 O.B. frequencies using a swept sine signal driving the transducer acoustic output at the maximum specified device audio input level and the maximum audio output volume setting.

Verification Success Criteria: The verification shall be considered successful when the test shows that the overall A-weighted levels are no greater than 115 dBA when converted to a diffuse field.

V-HLS-S-HMTA-0511 Continuous Noise Limits during Crew Sleep

Statement: Test and Analysis. The continuous noise during sleep shall be verified via test and analysis. Acoustic measurements shall be made within the vehicle in its flight configuration with integrated GFE, stowage, vehicle installations, and closeouts installed. Hardware shall be operated across the expected range of operational settings expected to occur during crew sleep, including settings corresponding to the expected highest continuous noise levels, and measurements shall be obtained at expected crew sleep head locations. Equivalent-continuous sound pressure level (Leq) measurements shall be made using a Type 1 integrating-averaging sound level meter with a 20-second averaging time. Leq measurements shall be reported for each octave band center frequency ranging from 63 Hz to 16 kHz. Measurement locations shall be no closer than 8 cm from any surface. Continuous noise generated by portable equipment, payloads, and cargo not included in the test shall be assumed to be equivalent to NC-36 and shall be analytically added to the measurement results. The analysis shall also document the design and operational parameters and mitigations implemented to achieve the as quiet as reasonably achievable (AQARA) principle during crew sleep periods.

Verification Success Criteria: The verification shall be considered successful when field testing and analysis indicate that the octave band Leq measurements obtained at each expected sleep station head location do not exceed the NC-50 octave band SPLs as indicated in Table C-11: Octave Band SPL Limits for Continuous Noise and the analysis shows that the AQARA principle is applied.

4.2.6 Ionizing Radiation

V-HLS-S-HMTA-0090 Ionizing Radiation Alerting

Statement: Test. Verification by test using a NASA GFE radiation area monitor simulated data stream.

Verification Success Criteria: Verification is considered successful for a manually set system alarm flag, when the system properly interprets and distributes that alert to all crew members. In addition, when the alarm flag is manually cleared, the system properly interprets and clears.

V-HLS-S-HMTA-0091 Natural Sunlight Exposure Limits

Statement: Analysis and Test. Crewmember exposure limits shall be verified by analyzed test data. The test shall measure the transmittance of all transparent and translucent apertures exposed to space and radiance of artificial sources from 180 nm–3000 nm, in 1- nm or 5-nm increments. Transmittance measurements shall be taken using witness coupons taken from each pane material, including applied coatings and/or laminates (in a flight-like configuration). The data representing components from multiple pane window designs should be mathematically combined to fully represent the completed window flight configuration transmittance (including coating orientation). The test data shall be provided to NASA in a common (non-proprietary), standardized data format (i.e., CSV files, DAT file, Excel, etc.). Spectral radiance measurements of artificial sources shall be performed by type and lot. The test data shall be provided to NASA, including the transmittance and radiance data in a common (non-proprietary), standardized data formats (i.e., CSV files, DAT file, Excel, etc.).and radiance of artificial sources from 180 nm–1,400 nm in 1-nm increments. Transmittance measurements may be taken using witness samples in the normal flight configuration if the witness samples are large enough to capture the enhanced transmittance realized from multi-pane reflections; otherwise, transmittance measurements shall be performed on flight articles. Spectral radiance measurements of artificial sources shall be done by type and lot. The test report shall be provided to NASA, including the transmittance and radiance data in easier to use data formats (i.e., CSV files, DAT file, Excel, etc.). The analysis shall be performed using the transmittance and radiance values obtained during the test.

Verification Success Criteria: The verification shall be considered successful when the analyzed test data shows that the exposure limits are satisfied per Table 4-2: Natural Sunlight Exposure Limits for Different Damage Mechanisms.

Table 4-2: Natural Sunlight Exposure Limits for Different Damage Mechanisms

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

*Injury TLVs from visible light presume a dark-adapted pupil with additional factors of safety applied. A minimum safety factor of 2 in the spectral radiance L_λ source terms has been included in the ACGIH standard. A minimum safety factor of 5 in the spectral irradiance E_λ source terms has been included in the ACGIH standard. To eliminate this excess conservatism, the requirement shall relax the spectral radiance L_λ by multiplying it by a factor of 1⁄2 and the spectral irradiance E_λ by multiplying it by a factor of 1⁄5. Thus, Equations 4a and 4b are subjected to the 2x relaxation factor, while Equation 8b is subjected to the 5x relaxation factor. This reduction does not apply to ultraviolet radiation. Thus, Equations 3 and 4 are not subjected to any relaxation factors.

These limits do not apply to laser exposure (see laser exposure limits). Older versions of the ACGIH TLVs shall not be utilized due to substantial differences in hazard functions. These limits do not account for forced chronic solar viewing.

V-HLS-S-HMTA-0093 Artificial Light Exposure Limits for Visible, Infrared (IR), and Ultraviolet (UV) Sources

Statement: Test or Analysis. Artificial Light Exposure Limits shall be verified by test or analysis. The test shall show the visible light source emissions are below 10,000 nits and the infrared/near-IR/UV light sources are at or below the TLV values as calculated per ACGIH, 2014 or later. The test shall be performed using a flight-representative test article or flight vehicle hardware, where flight-representative is defined as using hardware intended to be used in the flight vehicle but may not be the exact piece of hardware. The analysis shall show the visible sources that exceed 10,000 nits, and IR/near-IR sources are at or below the TLV values as calculated per ACGIH, 2014 or later.

Verification Success Criteria: Verification is considered successful when the test of the flight-representative test article or flight vehicle hardware shows visible sources do not exceed 10,000 nits and IR/near-IR/UV light sources are at or below the TLV values; OR

analysis per ACGIH (2014 or later) shows crew exposure to visible and IR/near-IR/UV sources does not exceed the TLV.

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

Statement: Analysis. Crew exposure to radio-frequency electromagnetic fields shall be verified by analysis. Data shall be analyzed and verified both for individual and combined RF EM fields. During operation, measurements shall be taken at internal and external locations that are accessible by the crew and compared to potential for crew exposure. (a) For exposures that are uniform over the dimensions of the body, such as certain far-field plane-wave exposures, the exposure field strengths and power densities are compared with the MPEs in the table. For non-uniform exposures, the mean values of the exposure fields, as obtained by spatially averaging the squares of the field strengths or averaging the power densities over an area equivalent to the vertical cross section of the human body (projected area) or a smaller area, depending on the frequency are compared with the MPEs in the table. For further details, see the notes to table 8 and table 9 of IEEE C95.1. (b) The left column is the averaging time for |E|2; the right column is the averaging time for |H|2. For frequencies greater than 400 MHz, the averaging time is for power density (S).
(c) These plane-wave equivalent power density values are commonly used as a convenient comparison with MPEs at higher frequencies and are displayed on some instruments in use.

Verification Success Criteria: The verification shall be considered successful when the analysis shows crew exposures are within the limits specified in Table 4-3 and HLS-RQMT-006, Figure C-10: Occupational Exposure Limits for Radio-Frequency Electromagnetic Fields illustrated to show body resonance effects around 100 MHz (modified from IEEE C95.1-2005 standard, lower tier). Note: The Crew RF Hazard Analysis Tool developed by the Space Radiation Analysis Group may be used to aid with RF hazard analyses for crew exposure and is available through NAMS request.

Table 4-3: Maximum Permissible Exposure (MPE) Limits for Radio-Frequency Electromagnetic Fields (modified from IEEE C95.1-2005 standard, lower tier)

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

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

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

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

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

V-HLS-S-HMTA-0096 Laser Exposure Limits

Statement: Analysis. Ocular and dermal exposure from laser systems shall be verified by analysis. The analysis shall be performed as defined by American National Standards Institute (ANSI) standard, ANSI Z136.1, 2014 “American National Standard for Safe Use of Lasers”. To prove that the ANSI standard is met, the laser system must be analyzed with regard to its operating parameters, operational configuration, and isolation and containment measures.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that ocular exposure is within the limits in ANSI Z136.1, 2014 Table 5 (ocular) and Table 7 (dermal).

V-HLS-S-HMTA-0097 Solar Particle Event (SPE) Protection

Statement: Analysis. Solar Particle Event protection shall be verified by analysis. The complexity of radiation environment, radiation transport calculations, and

vehicle/shielding geometry make verification by other methods intractable. Crew effective dose is assessed using a state-of-the-art radiation transport code to calculate the transport of the design SPE environment through the spacecraft and human tissue. A CAD model that accurately represents all of the spacecraft mass (vehicle structures, equipment, and supplies, as well as any additional radiation shielding materials) must be used for this assessment. A human phantom that accurately represents the distribution of tissue in each organ is also needed. Crew effective dose is calculated by first evaluating the dose equivalent at a large number of points in the human phantom, and then taking a weighted average of those values.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that the effective dose incurred by any crewmember within the vehicle does not exceed 250 mSv for the Design Reference SPE; and solar particle shielding design iterations per ALARA show calculated improvement in the mSv effective dose is less than 10 mSv from the previous iteration of the highest crew member's calculated exposure.

V-HLS-S-HMTA-0483 Radiation Data Reporting

Statement: Test and Inspection. The radiation reports to crew, as specified in HLS-RQMT-006, Table C-15: Radiation Data Reports, shall be verified by test and inspection.

Verification Success Criteria: The test and inspection shall be considered successful when the data reported to the vehicle data management system or equivalent are updated according to the report time and latency listed in HLS-RQMT-006, Table C-15: Radiation Data Reports.

4.3 Habitability Functions

4.3.1 Potable Water

V-HLS-S-HMTA-0034 Potable Water Physiochemical Limits

Statement: Test. Physiochemical water quality shall be verified by test. The test shall include a pre-flight evaluation of a fully integrated flight-equivalent water system for a length of time that encompasses the expected mission duration. Samples shall be collected from all points of crew consumption or contact to verify compliance. Samples shall be analyzed using standard laboratory techniques described in Standard Methods for the Examination of Water & Wastewater, American Public Health Association or approved alternate methodology that will provide equivalent data. Analytical methods that are not listed in Standard Methods for the Examination of Water and Wastewater must be approved by the JSC water quality group prior to use.

Verification Success Criteria: The verification shall be considered successful when test data demonstrate that the [system/vehicle] potable water system provides water at or

below the appropriate maximum concentrations listed in JSC 63414, Spacecraft Water Exposure Guidelines (SWEGs) or other applicable standard.

V-HLS-S-HMTA-0035 Potable Water Microbial Limits

Statement: Test. Microbiological water quality shall be verified by test. The test shall include evaluation of a fully integrated flight-equivalent water system for a length of time equal to the longest period expected between preflight preparation of potable water and postflight crew recovery. Samples shall be collected from all locations throughout the water system to which the crew may be exposed to verify compliance. These tests shall be conducted using standard laboratory techniques described in Standard Methods for the Examination of Water & Wastewater, American Public Health Association or alternate approved methodology that will provide comparable data. Analytical methods that are not listed in Standard Methods for the Examination of Water & Wastewater must be approved by the JSC microbiology group prior to use.

Verification Success Criteria: The verification shall be considered successful when test data are compliant with HLS-RQMT-006, Table C-16: Potable Water Microbiological Limits.

V-HLS-S-HMTA-0036 Potable Water Quantities and Temperatures

Statement: Analysis, Inspection, and Test. The provisioning of the specified quantity of potable water shall be verified by analysis. The analysis shall determine the amount of potable water stowage on the vehicle for the design reference mission utilizing maximum crew size and maximum mission duration. The capability of the vehicle to dispense hot, cold, and ambient water shall be verified by test. The analysis shall determine the amount of potable water stowage on the vehicle for the design reference mission utilizing maximum crew size and maximum mission duration.

Verification Success Criteria: The verification shall be considered successful when the analysis shows the Integrated Lander provides the minimum water quantities at selectable temperatures as specified in Table C-17 Potable Water Uses, Quantities, and Temperatures. The verification shall be considered successful when the test demonstrates that the system can dispense water in ALL of the temperature ranges specified in HLS-RQMT-006, Table C-17: Water Uses, Quantities, and Temperatures.

V-HLS-S-HMTA-0037 Water Dispensing Increments

Statement: Test. The capability of the vehicle to dispense water shall be verified by accurately dispensing water into a sampling of food and beverage items from the selected food system.

Verification Success Criteria: The verification shall be considered successful when the test shows that the water system allows crew to automatically dispense water in defined increments to properly rehydrate foods and beverages from the selected food system.

V-HLS-S-HMTA-0038 Water Dispensing Rate

Statement: Test. The potable water flow rate shall be verified by test.

Verification Success Criteria: The verification shall be considered successful when the test demonstrates that the system dispenses potable water at a rate that is compatible with the food system.

4.3.2 Food Accommodation

V-HLS-S-HMTA-0099 Food Preparation

Statement: Demonstration. A Demonstration shall be performed to show that the Integrated Lander accommodates all tasks necessary to prepare food for consumption, to consume the prepared food, and to stow the food and the instruments necessary to prepare and consume it. The demonstration shall be coordinated with HLS Joint Test Panel.

Verification Success Criteria: The verification shall be considered successful when the demonstration of the food preparation, consumption and stowage shows all foods can be prepared and consumed by the crew, and that food and instruments necessary for preparation and consumption can be stowed in the allotted volume.

V-HLS-S-HMTA-0101 Food Contamination Control

Statement: Inspection. Food contamination control shall be verified by inspection of CAD 3-D models to assess that design and locations of food storage, preparation, and consumption areas protect against cross-contamination.

Verification Success Criteria: The verification shall be considered successful when inspection shows that the design and location of the food system protects against cross-contamination between food and the environment.

V-HLS-S-HMTA-0102 Food and Beverage Heating

Statement: Demonstration and Test. Food and Beverage Heating shall be verified by demonstration and test. A demonstration should be performed to show the capability to select food and beverage temperatures. A test shall be performed to show that the selected temperature is reached. The demonstration shall be coordinated with HLS Joint Test Panel.

Verification Success Criteria: The verification shall be considered successful when demonstration shows that the crew can select a desired food and beverage temperature, and test shows that all items reached the selected temperature.

V-HLS-S-HMTA-0104 Food Facilities Cleaning and Sanitizing

Statement: Inspection. Food facilities and equipment cleaning and sanitizing shall be verified by inspection. An inspection shall be performed to show that the Integrated

Lander provides methods for cleaning and sanitizing of food facilities, equipment, and work areas.

Verification Success Criteria: The verification shall be considered successful when inspection shows that the Integrated Lander includes methods for performing the specified cleaning and sanitizing.

4.3.3 Design for Cleanliness

V-HLS-S-HMTA-0049 Surface Cleanability

Statement: Analysis. Surface cleanability shall be verified by analysis. The analysis shall include a review of the interior surfaces of the spacecraft.

Verification Success Criteria: The verification shall be considered successful when the analysis confirms that interior surfaces of the vehicle are made from materials that minimize microbial growth and are compatible with in-flight cleaning and disinfection.

V-HLS-S-HMTA-0052 Cross-Contamination

Statement: Inspection and Analysis. Functional biological cross-contamination control shall be verified through analysis and inspection. A crew task analysis shall be performed at the areas with activities that have higher potential for cross-contamination, including but not limited to food preparation, body waste management, and personal hygiene areas shall be evaluated to verify that the Integrated Lander allows for activities in these areas while limiting cross-contamination. CAD 3-D models of the vehicle layout showing the distance between these areas shall be inspected.

Verification Success Criteria: The verification shall be considered successful when analysis and inspection show that the Integrated Lander is capable of controlling cross-contamination among crew, vehicle habitat and systems, payloads, and planetary environments.

V-HLS-S-HMTA-0053 Availability of Environmental Hazards Information

Statement: Inspection. Availability of Environmental Hazards Information shall be verified by inspection.

Verification Success Criteria: Verification shall be considered successful when the inspection shows that the crew has environmental hazards information available under simulated flight conditions.

V-HLS-S-HMTA-0054 Contamination Cleanup

Statement: Inspection and Analysis. The ability of the Integrated Lander to remove or reduce contamination from the habitable volume shall be verified by inspection and analysis. NASA shall do an inspection of the crew task analysis performed during the design phase to ensure that all scenarios for contamination are addressed by the design

solution. An inspection of contamination control supplies shall determine whether adequate contamination control has been provided.

Verification Success Criteria: The verification shall be considered successful when inspection shows that an adequate crew task analysis was performed and a comprehensive set of hardware is provided to address the identified contamination scenarios. Due diligence in the identification of all possible contamination scenarios is essential to meeting this requirement. NASA spaceflight experience with dealing with onboard contamination contingencies must be incorporated. Exhaustive efforts to identify all scenarios will facilitate identification and use of proper hardware to address these scenarios.

V-HLS-S-HMTA-0055 Accessibility for Cleaning

Statement: Analysis. The ability of the crew to access areas for cleaning shall be verified via analysis and demonstration. A crew task analysis shall be performed to identify cleaning tasks and crew/vehicle configurations and environmental states. NASA shall do an inspection of the crew task analysis performed during the design phase to ensure that all scenarios for cleaning are addressed by the design solutions. A demonstration of representative tasks shall be performed in a high-fidelity 1g mockup by representative subjects jointly agreed upon by the JTP.

Verification Success Criteria: The verification shall be successful when the crew task analysis identifies all cleaning tasks as well as the crew/vehicle configurations and environmental states are considered in the design solutions. The demonstration shall be considered successful when subjects can perform representative tasks with acceptable success criteria jointly agreed upon by the JTP.

V-HLS-S-HMTA-0056 Particulate Control

Statement: Analysis and Demonstration. The ability of the Integrated Lander to remove of particulates shall be verified by via analysis and demonstration. A crew task analysis shall be performed to identify particulate control tasks as well as the crew/vehicle configurations and environmental states those tasks may be performed in. NASA shall do an inspection of the crew task analysis performed during the design phase to ensure that all scenarios for particulate control are addressed by the design solutions. A demonstration of representative tasks shall be performed in a high-fidelity 1g mockup by representative subjects jointly agreed upon by the JTP.

Verification Success Criteria: The verification shall be successful when the crew task analysis identifies all particulate control tasks as well as the crew/vehicle configurations and environmental states are considered in the design solutions. The demonstration shall be considered successful when subjects can perform representative tasks with acceptable success criteria jointly agreed upon by the JTP.

V-HLS-S-HMTA-0057 Cleaning Materials

Statement: Analysis and Test/Demonstration. The effectiveness, safety, and compatibility of cleaning materials shall be verified via test (or demonstration) and analysis. Effectiveness of the surface cleaning materials shall be verified by test (or demonstration). To verify that the surface cleaning materials are safe for human use and compatible with the water reclamation, air revitalization, and water management systems, the analysis shall include a review of the materials and chemicals selected.

Verification Success Criteria: The test/demonstration shall be considered successful when the surface cleaning materials are shown to perform as described in this standard rationale. The verification shall be considered successful when the analysis shows that the selected cleaning materials are Toxic Level 0 and are compatible with the spacecraft systems operations.

V-HLS-S-HMTA-0058 Hygiene Equipment Cleanliness

Statement: Analysis and Test. The provision of an environmentally compatible cleaning and sanitization method for personal hygiene facilities and equipment shall be verified by test and analysis.

Verification Success Criteria: The analysis shall be considered successful when it shows that the method is compatible with human health and with environmental control and life support (ECLSS) systems on the vehicles. The test shall be considered successful when hygiene equipment and facility surfaces can be visibly cleaned and sanitized to acceptable levels.

4.3.4 Personal Hygiene and Body Waste

V-HLS-S-HMTA-0105 Personal Hygiene Capability

Statement: Inspection and/or Demonstration. The capability for oral hygiene, personal grooming, and body cleansing shall be verified by inspection and/or HITL demonstration. An inspection of CAD modeling or flight representative mockup shall show accommodations for crew to perform oral hygiene, personal grooming, and body cleansing. The demonstration shall utilize a flight representative mockup in flight configuration with representative crew subjects to show that the accommodations can be used to perform personal hygiene tasks. The demonstration shall include subjective crew assessment of use in the gravitational environments applicable to Integrated Lander .

Verification Success Criteria: Verification shall be considered successful when the inspection and/or demonstration shows the Integrated Lander provides accommodations for performance of oral hygiene, personal grooming, and body cleansing.

V-HLS-S-HMTA-0108 Body Cleansing Privacy

Statement: Inspection. Design for body cleansing privacy shall be verified by inspection of drawings, CAD modeling, or high-fidelity mockup.

Verification Success Criteria: The verification shall be considered successful when drawings, CAD modeling, or high-fidelity mockup show that the body cleansing area is configured to provide privacy to crew when in use.

V-HLS-S-HMTA-0112 Body Waste Management System Location

Statement: Inspection and Analysis. Isolation of the body waste management system from other habitable areas of the vehicle shall be verified by inspection and analysis. Engineering drawings and models shall be inspected to verify that the body waste management system is isolated from other habitable areas of the vehicle, including work areas. Analysis of WMS operation, cleaning and maintenance activities and vehicle activities shall be conducted to show that the physical location of the WMS prevents cross contamination to other habitable areas of the vehicle during nominal operations.

Verification Success Criteria: The verification shall be considered successful when inspection of engineering drawings and models and analysis of WMS operations shows that the Integrated Lander design prevents interference between body waste management functions and other habitable areas of the vehicle.

V-HLS-S-HMTA-0113 Body Waste Management Privacy

Statement: Inspection. Crewmember privacy while using the body waste management system shall be verified by inspection. Engineering drawings and models shall be inspected to verify that crewmembers can achieve isolation while simulating usage of the body waste management system.

Verification Success Criteria: Verification shall be considered successful when the inspection show that the body waste management system provides privacy to the user during use.

V-HLS-S-HMTA-0114 Body Waste Management Provision

Statement: Analysis and Demonstration. Accessibility of supplies within reach while using the waste management system shall be verified by demonstration. The demonstration shall be performed by male and female subjects with flight-like hardware. The demonstration shall consist of test subjects reaching for and accessing body waste management personal hygiene supplies while using the system. The analysis shall extrapolate to the minimum and maximum critical dimensions of largest and smallest crewmember sizes.

Verification Success Criteria: Verification shall be considered successful when demonstration and analysis show that the crewmember using the waste management system can reach and access body waste management personal hygiene supplies during system use.

V-HLS-S-HMTA-0115 Waste Management System Odor Control

Statement: Demonstration and Test. Provision of odor control shall be verified by demonstration and test. A demonstration of odor control shall be performed in the flight configuration in a ventilation-controlled environment analogous to the flight ventilation-controlled environment for the expected duration of the mission. A test shall be conducted using an odor test panel during the demonstration to corroborate that odor is controlled for the expected mission duration.

Verification Success Criteria: The verification shall be considered successful when demonstration and test show that the body waste management system controls odors generated while collecting, storing and disposing of body waste.

V-HLS-S-HMTA-0116 Body Waste Trash Receptacle Accessibility

Statement: Analysis and Demonstration. Accessibility of a trash receptacle within reach while using the waste management system shall be verified by analysis and demonstration. The analysis shall extrapolate to the minimum and maximum critical dimensions of largest and smallest crewmember sizes. The demonstration shall be performed by male and female subjects with flight-like hardware. The demonstration shall consist of test subjects reaching for and accessing the trash receptacle while using the waste management system.

Verification Success Criteria: Verification shall be considered successful when demonstration shows that the crewmember using the waste management system can reach for and access the trash receptacle during use.

V-HLS-S-HMTA-0117 Private Body Inspection Accommodation

Statement: Demonstration. Crewmember privacy during private bodily self-inspection and cleaning shall be verified by demonstration. The demonstration shall be performed by male and female subjects with flight-like hardware. The demonstration shall consist of test subjects achieving visual isolation within sufficient volume while simulating private bodily self-inspection and cleaning.

Verification Success Criteria: The verification shall be considered successful when demonstration shows that the body waste management system provides visual privacy within sufficient volume to the user during private bodily self-inspection and cleaning.

V-HLS-S-HMTA-0118 Body Waste Management System Cleanliness

Statement: Analysis. Cleaning and sanitizing of the body waste management system and equipment shall be verified by analysis. Analysis shall show that the waste management system is compatible with cleaning and sanitization supplies.

Verification Success Criteria: The verification shall be considered successful when analysis shows that the body waste management system is compatible with the supplied cleaning and sanitization materials.

4.4 Crew Medical and Behavioral Health

V-HLS-S-HMTA-0119 Durable Medical Hardware and Supplies

Statement: Inspection and Demonstration. An inspection of the Medical Kit contents shall be performed against the NASA list of required durable medical hardware and supplies. A HITL demonstration shall be performed with flight representative, integrated Medical Kit subsystem to evaluate the operational usability for response to planned Integrated Lander medical scenarios, including data quality for crew and flight surgeon medical diagnosis.

Verification Success Criteria: The verification shall be considered successful when inspection and demonstration show that the Medical Kit provides the required durable medical hardware and supplies in an integrated system with NASA-provided pharmaceuticals and is usable by crew and ground-based physicians for planned Integrated Lander medical scenarios.

V-HLS-S-HMTA-0429 Medical Accessory Kits

Statement: Inspection. The Medical Accessory Kit shall be verified by inspection of CAD models and mass allocations data.

Verification Success Criteria: The verification shall be considered successful when inspection shows that Integrated Lander accommodates mass and volume of individual medical accessory kits in locations that support nominal and contingent medical and behavioral health needs.

V-HLS-S-HMTA-0120 Biological Waste Clean Up, Containment and Disposal

Statement: Analysis and Demonstration. Biological waste containment shall be verified by demonstration and analysis. The demonstration shall consist of disposing items, including biological waste, into the trash management system and showing that containment is complete and independent of gravity. The analysis shall show that the system is independent of gravity.

Verification Success Criteria: The verification shall be considered successful when the demonstration and analysis show that the trash management system contains these waste items.

V-HLS-S-HMTA-0122 Medical Sharps Disposal

Statement: Demonstration. Medical sharps containment shall be verified by demonstration. The demonstration shall consist of disposing items, including medical sharps, into the trash management system and showing that containment is safe, complete, and independent of gravity.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows that the trash management system contains these waste items.

V-HLS-S-HMTA-0123 Deceased Crew

Statement: Analysis and Inspection. The ability to handle deceased crewmembers shall be verified by analysis and inspection. The analysis shall state the plan for containing and preserving the deceased and the method of final disposition of remains. The inspection shall consist of a review to ensure that appropriate hardware is available and procedures are developed to contain and preserve remains until completion of final disposition of the remains.

Verification Success Criteria: The verification shall be considered successful when the inspection shows that the plan is developed, hardware is identified and available to contain, preserve and complete disposition of the remains.

V-HLS-S-HMTA-0489 Personal Behavioral Health (Off-Duty) Capabilities

Statement: Inspection and Demonstration. Personal Behavioral Health (Off-Duty) Capabilities shall be verified by inspection and demonstration. Inspection of CAD models and mass allocation data shall be performed to show accommodation of digital devices and peripherals, including power charging interfaces and audio and display interfaces, to support individual crew off-duty activities. Demonstration shall be performed to show data storage capability for digital media and the capability for crew to access and use desired media and e-mail communication.

Verification Success Criteria: The verification shall be considered successful when inspection of Master Equipment List and drawings shows that items that support behavioral and psychological health are provided in the vehicle, and/or the drawings identify stowage volume and restraint mechanisms, charging ports, connectors, and interface items in the vehicle that will accommodate crew personal devices and accessories (ear buds or headsets) and demonstration confirms compatibility of the stowage and charging ports, connectors and interface items with personal computing devices.

4.5 Cabin Architecture

4.5.1 Cabin Volume and Layout

V-HLS-S-HMTA-0106 Crew Mission Volume and Layout

Statement: Analysis, Inspection, and Test. Crew mission volume shall be verified by analysis, inspection, and demonstration. Iterative process of design, analysis and test should follow the process outlined by JSC/SA/Chief Medical Officer in Memo SA-16-156. A crew task analysis shall be performed to identify crew tasks required for nominal and off-nominal operation. An analysis shall be performed to show functional arrangement and allocation of volumes to support crew operations are consistent with the anthropometric and range of motion data. The inspection shall include the review of CAD 3D models showing vehicle layout accommodation of expected crew tasks, anthropometry and range of motion. A HITL test shall utilize flight representative mockup/hardware in flight configuration(s) with representative subjects in flight

configuration performing selected critical mission tasks (e.g., waste & hygiene, food prep, sleep, medical treatment, lunar dust cleaning, housekeeping), as agreed to through JTP, to evaluate operability and usability of volume and layout.

Verification Success Criteria: The verification shall be considered successful when the analysis, inspection, and test show that the Integrated Lander provides defined functional volumes, habitable space, and layout that support performance of crew work and personal tasks.

V-HLS-S-HMTA-0154 Spatial Orientation

Statement: Inspection. Design of consistent local orientation shall be verified by inspection of crew task analysis and cabin layout drawings, CAD modeling, or high-fidelity mockup.

Verification Success Criteria: The verification shall be considered successful when inspection shows that a local orientation is established and work areas and interfaces have consistent orientation.

V-HLS-S-HMTA-0157 Location Identifiers

Statement: Inspection. Design for consistent local orientations shall be verified by inspection of labeling plan, drawings, CAD modeling, or high-fidelity mockup.

Verification Success Criteria: The verification shall be considered successful when the labeling plan, drawings, CAD modeling, or high-fidelity mockup show that location coding is implemented to identify defined locations, such as stowage and work areas, and spatial orientation.

4.5.2 Translation Pathways

V-HLS-S-HMTA-0160 IVA Translation Paths

Statement: Inspection, Analysis, and Demonstration. Design of internal translation paths shall be verified by inspection of crew task analysis, worksite analysis, and HITL demonstration of select tasks.

Verification Success Criteria: The verification shall be considered successful when inspection, analysis, and HITL demonstration show that IVA translation paths are designed to allow movement of crew and equipment in operational configurations.

V-HLS-S-HMTA-0162 Emergency Ingress and Egress Translation

Statement: Inspection and Demonstration. Design of emergency ingress and egress translation pathways shall be verified by inspection of crew task analysis and cabin layout drawings or CAD modeling, and HITL demonstration of selected emergency translation tasks.

Verification Success Criteria: The verification shall be considered successful when inspection and HITL demonstration show that the cabin interior layout includes translation paths for emergency ingress and egress that are visible and allow for unimpeded movement of crew in their operational configuration within time required as defined in crew task analysis.

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

Statement: Analysis and Demonstration. The translation path for the assisted in-space ingress and egress of an incapacitated pressurized-suited crewmember shall be verified by analysis and demonstration. The analysis shall consist of volumetric modeling of the in-space translation path and human models of the incapacitated crewmember and the assisting crewmembers. The demonstration shall consist of a high-fidelity mockup or flight vehicle and use of a simulated pressurized-suited and unsuited crewmember with weight representative of the applicable gravity environment and the assisting crewmembers.

Verification Success Criteria: The verification shall be considered successful when the analysis and demonstration prove that the in-space translation path provides sufficient clearance for the assisted ingress and egress of an incapacitated crewmember.

4.5.3 Crew Restraint and Mobility Aids

V-HLS-S-HMTA-0182 Crew Restraints for Task Performance

Statement: Inspection, Analysis, and Demonstration. Design of crew restraints for task performance shall be verified by inspection of crew task analysis, worksite analysis, and HITL demonstration of select tasks.

Verification Success Criteria: The verification shall be considered successful when inspection, analysis, and HITL demonstration show that restraints are provided to support crew in successfully completing tasks.

V-HLS-S-HMTA-0183 Restraints for Crew Protection

Statement: Inspection and Demonstration. The design of crew restraints to protect crew during dynamic vehicle movement shall be verified by inspection of crew task analysis to identify tasks to be performed under dynamic accelerations; inspection of drawings, CAD modeling, or high-fidelity mockup; and HITL demonstration of selected crew tasks.

Verification Success Criteria: The verification shall be considered successful when the inspection and demonstration show that crew restraints are provided to protect crew during dynamic phases of vehicle movement.

V-HLS-S-HMTA-0189 Crew Mobility Aids for Task Performance

Statement: Inspection, Analysis, and Test. Crew task analysis shall identify type, location, and interfaces for mobility aids needed to support crew tasks. The analysis shall also determine the Anthropometric Dimensions and Range of Motion for body

reach, fit, and clearance and Type of Strength that crew will apply when performing tasks with mobility aids. Inspection of drawings, CAD modeling, or flight representative mockup shall confirm that mobility aids are implemented to support crew tasks and the range of anthropometric dimensions. HITL test shall utilize a flight representative mockup in the flight configuration with subjects in flight configurations performing select tasks, as agreed to through JTP, to evaluate usability of mobility aids. Analysis and/or test shall confirm that mobility aids will withstand Maximum Crew Operational Loads, defined in HLS-PAP-001 Physical Characteristics and Capabilities Dataset for the task type of strength identified through crew task analysis.

Verification Success Criteria: The verification shall be considered successful when inspection, analysis, and test show that mobility aids are provided to support crew task performance.

4.5.4 Sleep Accommodation

V-HLS-S-HMTA-0145 Sleep Accommodation

Statement: Analysis, Inspection, and Demonstration. Design for sleep accommodation shall be verified by worksite analysis and inspection of drawings, CAD modeling, and demonstration in a high-fidelity mockup.

Verification Success Criteria: The verification shall be considered successful when worksite analysis and/or high-fidelity mockup inspection and demonstration shows that sleep accommodations are provided for each crewmember include: Appropriate volume, surface, and restraints for relevant gravity environments; design features that limit vibration, limit visual and auditory stimulation; crew controls for lighting and temperature.

V-HLS-S-HMTA-0146 Partial-g Sleeping

Statement: Inspection and Demonstration. Partial-g Sleeping shall be verified by inspection of drawings, CAD modeling, and/or high-fidelity mockup inspection and demonstration.

Verification Success Criteria: The verification shall be considered successful when inspection and demonstration shows that horizontal sleep surfaces are provided for partial-g mission environments.

4.5.5 Stowage and Inventory Management

V-HLS-S-HMTA-0124 Stowage Provisions

Statement: Inspection and Test. Inspection of drawings and component/sub-system test reports shall be performed to show that hardware, supplies, and crew personal items have defined stowage locations that accommodate their applicable stowage parameters (e.g., protect from expected gravity, acceleration and vibration conditions, provides required temperature and pressure environment) and crew operational needs

(e.g., stowage location and layout for frequently accessed and priority need items). HITL test of selected crew tasks requiring access to stowed items shall be performed in high-fidelity physical mockup with test subjects performing task procedures to measure usability (e.g., reach, clearance, strength to operate mechanisms) and task performance time.

Verification Success Criteria: Verification shall be considered successful when the inspection shows the hardware, supplies, and crew personal items have defined stowage locations accommodating priority access needs and required environmental conditions; and test shows that critical and emergency use items can be accessed and unstowed within time required for crew operational response.

V-HLS-S-HMTA-0128 Deployed Item Restraints

Statement: Inspection and Test. Design of restraints for deployed items shall be verified by inspection of crew task analysis, inspection of drawings or CAD modeling, and HITL test of selected crew tasks requiring removal and deployment of stowed items shall be performed in high-fidelity physical mockup with test subjects performing task procedures to measure usability (e.g., reach, clearance, interference, strength to operate mechanisms, etc.) of item restraints. Usability evaluations should include collection of data such as completion times and ratings on subjective questionnaires that will help identify task or interface design or procedure problems. For the usability evaluation, a task is defined as an activity driven by a procedure. The procedure consists of a series of task steps, where a task step is defined as a single instruction to the crewmember, as is typical of current spaceflight procedures.

Verification Success Criteria: verification shall be considered successful when the inspection and HITL test show that the system provides restraints for unstowed and deployed items that support crew task performance.

V-HLS-S-HMTA-0132 Inventory Tracking

Statement: Inspection and Demonstration. Inspection of the Artemis Compatible Inventory Management System (IMS) shall show that the system identifies items using operational nomenclature consistent with item labeling. Demonstration of the IMS shall show that the system allows the crew and Mission Systems to accurately and efficiently track the locations, quantities, and operational data/constraints of items in stowage, from pre-launch planning through mission execution.

Verification Success Criteria: Verification shall be considered successful when inspection and demonstration show that the Artemis Compatible IMS allows the crew and Mission Systems to accurately and efficiently track the locations, quantities, and operational data/constraints of items in stowage (from pre-launch planning through mission execution), and that the Artemis compatible IMS identifies items using operational nomenclature consistent with item labeling.

4.5.6 Trash Management

V-HLS-S-HMTA-0138 Trash Accommodation

Statement: Inspection. The Integrated Lander accommodation of wet and dry trash shall be verified by inspection. Inspection shall examine the crew task analysis for identification of trash-generating activities, trash types, and associated trash locations. An inspection of drawings, modeling, or mockup shall confirm implementation of trash accommodation.

Verification Success Criteria: Verification shall be considered successful when the inspection shows that Integrated Lander can accommodate all wet and dry trash, as determined through crew task analysis.

V-HLS-S-HMTA-0139 Trash Volume Allocation

Statement: Inspection. Trash Volume Allocation shall be verified by inspection. Inspection of drawings, CAD modeling, or mockup shall confirm that trash stowage locations with needed volume are provided.

Verification Success Criteria: Verification shall be considered successful when the inspection shows that the Integrated Lander defines and has allocated volume for trash.

V-HLS-S-HMTA-0141 Trash Odor Control

Statement: Analysis and Demonstration. The odor control for trash management equipment shall be verified by analysis and demonstration with subjective evaluation. Analysis shall identify and characterize trash types and odors and detail the trash containment designs. Demonstration shall be performed using flight-representative trash containers and representative odor sources. The demonstration shall be performed under representative environmental conditions (e.g., vehicle habitable volume, temperature, humidity, airflow, etc.), while exercising expected trash operations for the duration expected until trash disposal. NASA crew and/or SMEs will provide subjective evaluation (e.g., discomfort scale) as the measure of whether odors are contained during the demonstration.

Verification Success Criteria: The verification shall be considered successful when analysis and demonstration evaluation show that the trash management system controls odors from permeating the habitable volume of the vehicle.

V-HLS-S-HMTA-0142 Trash Contamination Control

Statement: Analysis. The prevention of trash release shall be verified by analysis. The analysis shall include a review of the trash management system design. The analysis shall examine date samples gathered from the surrounding environment after repeated operations of the trash management system where microorganisms are present.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that microorganisms in trash are not released outside of the trash management system.

4.5.7 Hatches

V-HLS-S-HMTA-0171 Hatch Operation without Tools

Statement: Demonstration. Hatch operability without the use of tools shall be verified by demonstration. The demonstration shall occur in a qualification vehicle or a high-fidelity mockup, and the vehicle or mockup shall be in the flight configuration with integrated GFP, stowage, vehicle installations, and closeouts installed. The demonstration shall consist of one suited subject performing the following four tasks: unlatching and fully opening each hatch from the inside, unlatching and fully opening each hatch from the outside, closing and latching each fully-opened hatch from the inside, and closing and latching each fully-opened hatch from the outside. The demonstration task completion time shall be measured in seconds.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows that the hatch is operable without the use of tools.

V-HLS-S-HMTA-0172 Unlatching Hatches

Statement: Demonstration. Hatch unlatching shall be verified by demonstration. The demonstration shall be performed in a flight-representative vehicle with the hatch and crew in the flight configuration.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows that unlatching requires two distinct and sequential operations.

V-HLS-S-HMTA-0173 Hatch Operating Times

Statement: Demonstration. Hatch operability in 60 seconds shall be verified by demonstration. The demonstration shall occur in a qualification vehicle or a high-fidelity mockup, and the vehicle or mockup shall be in the flight configuration with integrated GFP, stowage, vehicle installations, and closeouts installed. The demonstration shall demonstrate 0-g operability by performing the tasks in 1 g and applying a 0-g factor to the task completion time. The demonstration shall consist of one suited subject performing the following four tasks: unlatching and fully opening each hatch from the inside, unlatching and fully opening each hatch from the outside, closing and latching each fully-opened hatch from the inside, and closing and latching each fully-opened hatch from the outside. The demonstration task completion time shall be measured in seconds.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows that the completion time is 60 seconds or less per task.

V-HLS-S-HMTA-0174 Hatch Operating Force

Statement: Analysis, Test, and Demonstration. The hatch operating forces shall be verified by analysis, test, and demonstration. The force required to perform full hatch opening shall be measured using a force strain gauge through all steps of opening the hatch including hatch retention mechanisms, crank operation to fully unlatch, and opening/removing the hatch. Analysis shall be performed to account for pressure differential, gravity, or orientation impacts on hatch operation. The demonstration shall utilize a flight representative mockup in the flight configuration with subjects, representing the range of sizes in representative flight configuration, to evaluate crew postures and their ability to apply necessary strength types to operate hatches in expected vehicle orientations.

Verification Success Criteria: The verification shall be considered successful when analysis, demonstration, and test show that crew will be able to apply necessary postures and strength types to operate hatches in expected vehicle orientations and the forces required to fully open and close hatches are no greater than the maximum crew operational loads for the type of strength that crew will use to operate hatches under expected vehicle orientations and gravity conditions.

V-HLS-S-HMTA-0176 Hatch Size and Shape

Statement: Analysis and Demonstration. Hatch size and shape shall be verified by analysis and demonstration. Analysis shall identify operation scenarios where crew in their operational configuration (e.g. not suited, suited, carrying cargo or equipment) must translate through a hatch or doorway in order to accomplish a planned task. This includes suited operation scenarios for crew ingress and egress (nominal and off-nominal) from one vehicle or transfer between two, including the likely pressurization state of spacesuits. Analysis shall consist of using high-fidelity computer graphic models. The models shall include the vehicles and movement of crew in their operational configuration through the translation paths. The demonstration shall utilize a flight representative mockup in the flight configuration with subjects, representing the range of sizes in representative flight configuration, to evaluate translation through hatches and doorways in operations scenarios that are based on planned tasks.

Verification Success Criteria: The verification shall be considered successful when the analysis and demonstration show that crew in operational configuration can pass through hatches and doorways to complete planned tasks without interference and without being hampered by protrusions and snag points.

V-HLS-S-HMTA-0177 Pressure Equalization

Statement: Analysis and Demonstration. Manual pressure equalization on each side of the hatch shall be verified by analysis and demonstration. Analysis shall include identifying suited operation scenarios including the likely pressurization state of spacesuits. The demonstration shall occur in the vehicle or a high-fidelity mockup. The demonstration shall consist of performing a manual pressure equalization procedure on both sides of each hatch under the range of expected internal/external pressure levels.

Verification Success Criteria: The verification shall be considered successful when the analysis and demonstration show that a suited crewmember can complete the procedure.

V-HLS-S-HMTA-0178 Visibility Across the Hatch

Statement: Inspection and Demonstration. Visibility across hatches shall be verified by inspection of drawings and demonstration.

Verification Success Criteria: The verification shall be considered successful when the inspection and demonstration show that crewmembers are able to have direct, non-electronic visual observation of the environment on the opposite side of the hatch.

V-HLS-S-HMTA-0179 Hatch and Door Interference

Statement: Analysis and Demonstration. Translation paths shall be verified by analysis and demonstration. Analysis shall include identifying suited operation scenarios for crew ingress and egress (nominal and off-nominal) from one vehicle or transfer between two, including the likely pressurization state of spacesuits. Analysis shall consist of using high-fidelity computer graphic models. The models shall include the vehicles, suited crewmembers, and suited crewmembers' movement through the translation paths. The demonstration shall occur in a high-fidelity mockup in 1g in the flight configuration with integrated GFP, stowage, vehicle installations, and closeouts installed. The demonstration shall consist of suited subjects performing ingress and egress (nominal and off-nominal) operation scenarios.

Verification Success Criteria: The verification shall be considered successful when the analysis and demonstration show that suited ingress and egress (nominal and off-nominal) operations can be performed without being hampered by protrusions and snag points.

V-HLS-S-HMTA-0180 Hatch Closure and Latching Status Indication

Statement: Demonstration. Hatch closure and open status shall be verified by demonstration. The demonstration shall occur in a qualification vehicle or a high-fidelity mockup. The demonstration shall consist of the following tasks: opening the hatch and identifying that the hatch closure status indicates that the hatch is open and closing the hatch and identifying that the hatch closure status indicates that the hatch is closed.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows that the hatch closure and open status is displayed from each side of each hatch.

V-HLS-S-HMTA-0181 Hatch Pressure Indication

Statement: Test. Pressure difference measurement shall be verified by test. The test shall occur in a qualification vehicle or high-fidelity mockup. The test shall consist of one subject performing the pressure difference measurement on both sides of each hatch under the range of expected internal/external pressure levels.

Verification Success Criteria: The verification shall be considered successful when the test shows that all pressure differences are measured on each side of the vehicle.

4.5.8 Windows

V-HLS-S-HMTA-0196 Viewing Exterior Operations

Statement: Inspection, Analysis, and Demonstration. The provision of an external observation window shall be verified by inspection of the engineering drawings and data packs for the lead flight article, followed by inspection of engineering drawings and data packs only for subsequent articles. The functionality of the external observation window shall be verified by analysis and demonstration. A crew task analysis shall be performed to determine the method for critical viewing operations (i.e. camera or window). The demonstration shall evaluate a representative set of critical viewing tasks using representative subjects.

Verification Success Criteria: If a window is used, the verification shall be considered successful when the inspection shows that a window has been provided for external observation and that the analysis and demonstration show that the system window provides the optical characteristics and field-of-view appropriate to its tasking per JSC 63320, Optical Property Requirements for Glasses, Ceramics and Plastic in Spacecraft Window Systems. Verification shall be considered successful when the inspection shows the correlating deliverables for the requirements have been approved by NASA. If cameras are used, the verification shall be considered successful when the analysis shows that the crew monitoring system can meet the performance requirements with the required level of fault tolerance during all phases of flight in which it is used.

V-HLS-S-HMTA-0199 Window Light Blocking

Statement: Demonstration and Test. Window Light Blocking shall be verified by demonstration and test. The demonstration shall ensure window coverings (e.g. shades and filters) are installed and removed without tools. The test shall utilize simulated sunlight on the exterior of the vehicle and light blocking in place.

Verification Success Criteria: The verification shall be considered successful when the test shows window light blocking reduces interior light level to 2 lux at 0.5 m (20 in) from each window, and the demonstration shows that window coverings (e.g. shades and filters) can be installed and removed without the use of tools.

4.5.9 Lighting

V-HLS-S-HMTA-0201 Spacecraft Lighting

Statement: Analysis, Test, and Demonstration. Spacecraft Lighting shall be verified by Analysis, Test, and Demonstration. The crew task analysis shall identify illumination levels needed for crew visual tasks. Test shall be performed to measure illumination levels for critical crew tasks. HITL demonstration shall be performed for critical and

frequent crew visual task scenarios under flight-like configurations to assess effectiveness and acceptability of lighting.

Verification Success Criteria: Verification shall be considered successful when measured illumination levels for critical crew tasks meet the levels identified in the crew task analysis, and demonstration shows crew assess the lighting as acceptable and can effectively perform critical visual tasks.

V-HLS-S-HMTA-0204 Emergency Lighting

Statement: Analysis, Test, and Demonstration. The emergency lighting system shall be verified by analysis, test and demonstration. A crew task analysis shall determine the operations required for operational recovery and crew egress. The test shall evaluate automatic activation of emergency lighting, including unpowered illumination sources (e.g., photoluminescent decals), by interrupting primary vehicle power and measuring elapsed time to activation of emergency lighting. a demonstration shall be performed of the operational recovery tasks and crew egress in a lighting failure.

Verification Success Criteria: The verification shall be considered successful when test shows that emergency lighting is automatically activated, within 1-second of power loss, and demonstration shows illumination levels support operational recovery activities and crew egress.

V-HLS-S-HMTA-0207 Circadian Entrainment

Statement: Test. Circadian Entrainment shall be verified by test. The test shall be a levels of light test in accordance with HLS-RQMT-006, Table C-18: Physiological Lighting Specifications.

Verification Success Criteria: This verification shall be successful when the levels of light are in accordance with HLS-RQMT-006, Table C-18: Physiological Lighting Specifications.

V-HLS-S-HMTA-0208 Lighting Controls

Statement: Demonstration. Operation of the On/Off and dimmer control to prevent and restore light emission by the lights shall be verified by demonstration. The demonstration shall consist of turning the control to ‘on’, ‘off’, and to ‘dim’ to adjust the light levels. Demonstration with the dimming capabilities shall also be completed for task conditions.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows that the lights are capable of on/off and dimmer abilities.

V-HLS-S-HMTA-0210 Glare & Shadows

Statement: Demonstration. Control of glare & shadows shall be verified by HITL demonstration. The demonstration shall utilize a flight representative mockup in the flight configuration with representative crew subjects in representative flight

configurations performing select tasks, as agreed to through JTP, to evaluate glare and shadow impacts on crew task performance.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows that glare and shadows do not impact task performance.

4.6 Crew Safety

4.6.1 Mechanical Hazards

V-HLS-S-HMTA-0212 Entrapment

Statement: Analysis and Demonstration. The protection of crew from entrapment shall be verified through analysis and demonstration. An analysis shall be performed to identify potential sources for entrapment and their designed control measures. Demonstration of crew motion restraints shall be performed using flight representative retention systems to verify that crewmembers are able to release fasteners under simulated nominal and emergency conditions.

Verification Success Criteria: The verification shall be considered successful when analysis and demonstration show that potential entrapment sources are controlled and that crew can release from motion restraints.

V-HLS-S-HMTA-0213 Stored Energy Release

Statement: Analysis. The protection of crew from stored potential energy shall be verified through analysis. An analysis shall be performed to identify stored energy sources and their control measures preventing their uncontrolled release.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that stored energy sources are inaccessible to crew or have acceptable control measures during all operational phases to prevent injury.

V-HLS-S-HMTA-0214 Protection from Projectiles

Statement: Inspection, Analysis, and Test. Protection from Projectiles shall be verified by inspection, analysis, and test. The inspection shall include a review of design, models, mockups, hazard analysis, and planned contingencies analysis results to ensure protection and controls are in place. An analysis to identify applicable dynamic phases of flight and assess injury risk shall be performed. Tests to show flight representative systems prevent injury, such as penetrating wounds or bruises, to the occupants shall also be included.

Verification Success Criteria: The verification shall be considered successful when the inspection, analysis, and test show that the configuration of the hardware mounting, habitat enclosures, and applicable systems, protect the crew from projectiles in the event of sudden changes in acceleration or collisions.

V-HLS-S-HMTA-0216 Isolation of Crew from Spacecraft Equipment

Statement: Analysis. Isolation of crew from spacecraft equipment shall be verified by analysis. The Worksite Analysis shall include CAD 3D models that show integration of protective provisions into the vehicle architecture to separate equipment from the crew in the habitable volume.

Verification Success Criteria: The verification shall be considered successful when the Worksite Analysis shows that protective provisions are in place to separate equipment from the crew in the habitable volume.

V-HLS-S-HMTA-0217 Sharp Corners and Edges - Fixed

Statement: Inspection. Sharp corners and edges – fixed shall be verified by inspection. The inspection shall be performed of the drawings as well as as-built hardware for rounding specifications of corners and edges that are exposed to crew during nominal operations.

Verification Success Criteria: The verification shall be considered successful when the inspection confirms the exposed corners and edges meet the roundness specified in the requirement.

V-HLS-S-HMTA-0218 Protection from Functionally Sharp Items

Statement: Analysis and Inspection. Protection from functionally sharp items shall be verified by analysis and inspection. The analysis shall include identification of physical control measures for preventing crew injury from functionally sharp items when not in use and inspection of the as-built hardware configuration for control measures when not in use.

Verification Success Criteria: The verification shall be considered successful when the inspection of the as-built hardware confirms the inclusion of the control measures to prevent crew injury from functionally sharp items when not in use as analyzed.

V-HLS-S-HMTA-0219 Sharp Corners and Edges - Loose

Statement: Inspection. Sharp corners and edges – loose shall be verified by inspection. The inspection shall be performed of the drawings as well as as-built loose equipment for rounding specifications of corners and edges that are exposed to crew during normal operations.

Verification Success Criteria: The verification shall be considered successful when the inspection confirms the exposed corners and edges meet the roundness specified in the requirement.

V-HLS-S-HMTA-0220 Burrs

Statement: Inspection. Burrs shall be verified by inspection. The inspection shall be performed of as-built hardware for burrs on surfaces that are exposed to crew.

Verification Success Criteria: The verification shall be considered successful when the inspection confirms the exposed surfaces are free of burrs.

V-HLS-S-HMTA-0221 Pinch Points

Statement: Analysis and Inspection. Pinch points shall be verified by analysis and inspection. The analysis shall include identification of control measures for preventing crew injury from potential accessible pinch points and inspection of the as-built hardware configuration for control measures.

Verification Success Criteria: The verification shall be considered successful when the inspection of the as-built hardware confirms the inclusion of the control measures to prevent crew injury from accessible pinch points as analyzed.

4.6.2 Touch Temperature Hazards

V-HLS-S-HMTA-0222 Touch Temperature Upper Limit

Statement: Analysis and Test. High-Temperature Exposure shall be verified by test and analysis. Test shall be conducted to measure temperature of hot surfaces that are exposed to crew contact. Where TES > 45ºC (113ºF), an analysis shall be performed to determine maximum TPM for those exposed surfaces.

Verification Success Criteria: The verification shall be considered successful when test and/or analysis show that temperatures for exposed surfaces are lower than TPM and appropriate hazard control measures are implemented. TPM shall be calculated as follows:

When calculating TPM for intentional contact, a minimum time of 10 seconds applies. Where contact time for nominal operations is planned to exceed 10 seconds, time increments for up to 30 seconds, up to 60 seconds, or infinite time are to be used. Because contact time is a factor in establishing permissible material temperature, consider the following if there is potential for exceeding planned contact time: Either calculate TPM using higher or infinite contact time, especially if there may be an adverse consequence due to unplanned release of an object, or inform crewmembers of the contact time limit via an operational control that has been coordinated with the operations community.

The equation for TPM assumes the object material is homogeneous. If the object is a layup of different materials (i.e., is comprised of layers), TPM is to be calculated using the thermophysical properties of the material with lowest value for inverse thermal inertia. Alternately, with justification, TPM may be calculated using the thermophysical properties of the material in the layup that is the largest contributor to the change in skin temperature. Refer to the NASA/SP-2010-3407, Human Integration Design Handbook (HIDH) for additional guidance on calculating TPM. Figure 4-1: Hot Touch Temperature Limits illustrates hot TPM for incidental and intentional (planned) contact and four common materials.

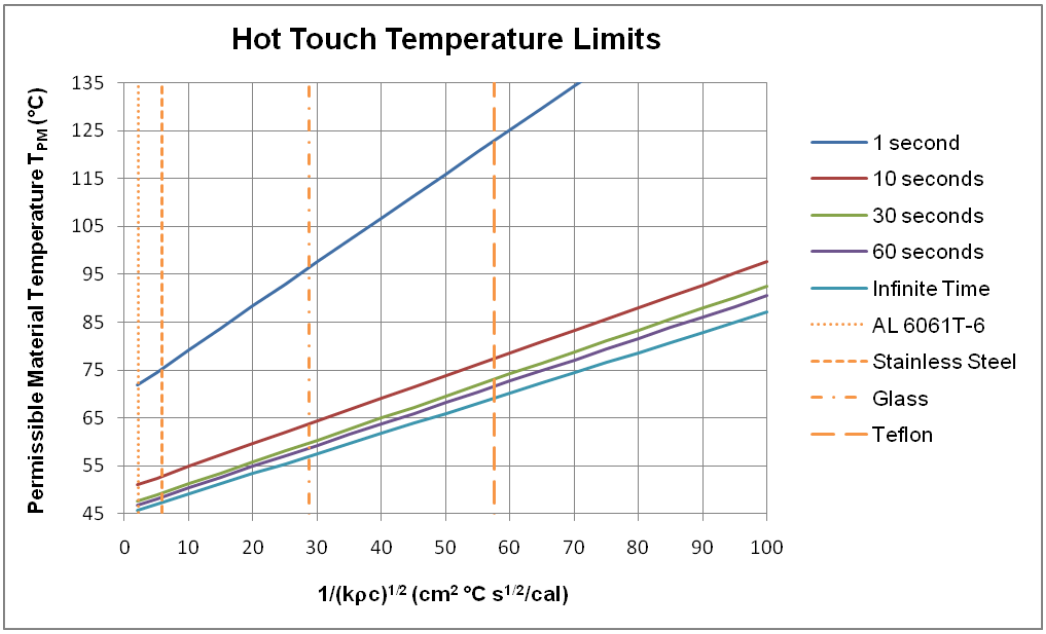

Figure 4-1: Hot Touch Temperature Limits

1. For *incidental* contact, defined as contact time $t \leq 1$ second:

$$T_{PM}\,(°C) = a * (k\rho c)^{-½} + b$$

Where:

$(k\rho c)^{-½}$ = inverse thermal inertia of material (cm^2 °C sec½)/cal (Table 4-4: Inverse Thermal Inertia for Commonly Used Materials)

a = 0.92
b = 69.97

2. For *intentional* contact, defined as planned skin contact for any length of time:

$$T_{PM}\,(°C) = a * (k\rho c)^{-½} + b$$

Where:

$(k\rho c)^{-½}$ = inverse thermal inertia of material (cm2 °C sec½)/cal (Table 4-4: Inverse Thermal Inertia for Commonly Used Materials)

a, b = constants in Table 4-5: Hot Temperature Constants for Intentional (Planned) Contact

Table 4-4: Inverse Thermal Inertia for Commonly Used Materials

Material	Inverse Thermal Inertia $(k\rho c)^{-½}$ $((cm^2\ °C\ sec^{1/2})/cal)$
Aluminum (6061T-6)	2.2
316 Stainless Steel	5.9
Glass	28.8
Teflon	57.5
Nylon Hook Velcro	586 (effective)
k = thermal conductivity, ρ = density, c = specific heat	

Table 4-5: Hot Temperature Constants for Intentional (Planned) Contact

Contact Time (s)	a	b
10	0.48	50.07
30	0.46	46.61
60	0.45	45.90
∞	0.42	44.87
Note: for intentional contact, a minimum time of 10 seconds applies when calculating T_{PM}.		

V-HLS-S-HMTA-0223 Low Temperature Exposure Limit

Statement: Analysis and Test. Low Temperature Exposure shall be verified by test and analysis. Test shall be conducted to measure temperature of cold surfaces that are exposed to crew contact. Where TES ≤ 0ºC (32ºF), analysis shall be performed to determine the minimum TPM for those exposed surfaces.

Verification Success Criteria: The verification shall be considered successful when test and/or analysis show that temperatures for exposed surfaces are higher than TPM and appropriate hazard control measures are implemented. TPM shall be calculated as follows:

When calculating TPM for intentional contact, a minimum time of 10 seconds applies. Where contact time for nominal operations is planned to exceed 10 seconds, time increments for up to 30 seconds, up to 60 seconds, or infinite time are to be used. Because contact time is a factor in establishing permissible material temperature, consider the following if there is potential for exceeding planned contact time:

Either calculate TPM using higher or infinite contact time, especially if there may be an adverse consequence due to unplanned release of an object, or inform crewmembers of the contact time limit via an operational control that has been coordinated with the Operations community.

The equation for TPM assumes the object material is homogeneous. If the object is a layup of different materials (i.e., is comprised of layers), TPM is to be calculated using the thermophysical properties of the material with lowest value for inverse thermal inertia. Alternately, with justification, TPM may be calculated using the thermophysical properties of the material in the layup that is the largest contributor to the change in skin temperature. Refer to the NASA/SP-2010-3407, Human Integration Design Handbook (HIDH) for additional guidance on calculating TPM. Figure 4-2: Cold Touch Temperature Limits illustrates cold TPM for incidental and intentional (planned) contact and four common materials.

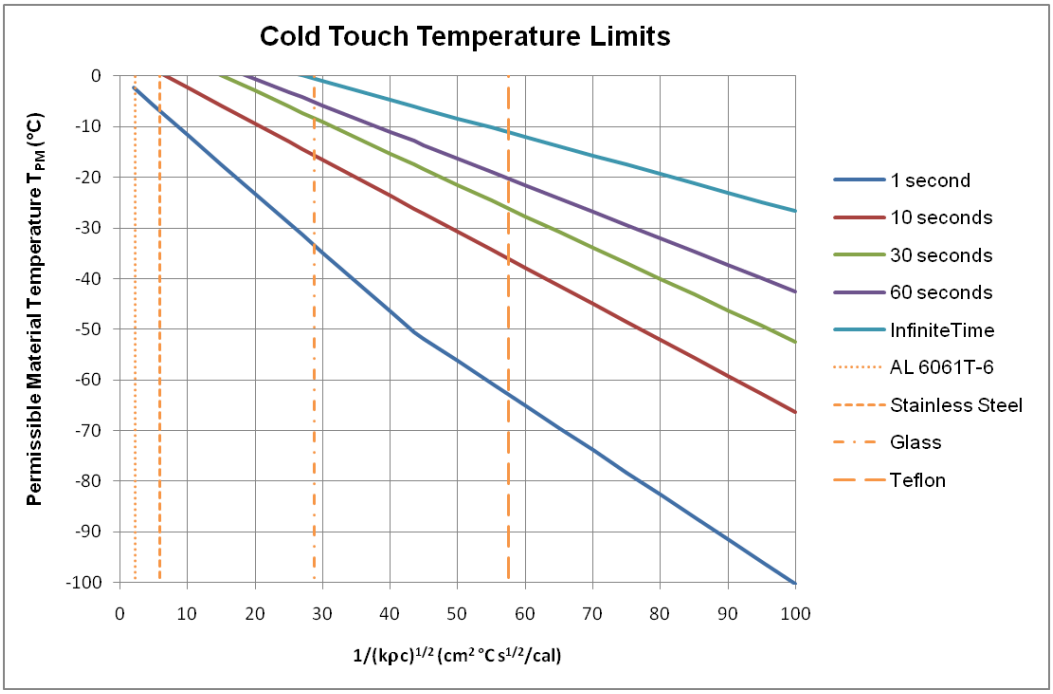

Figure 4-2: Cold Touch Temperature Limits

1. For *incidental* contact, defined as contact time $t \leq 1$ second:

$$T_{PM}\,(°C) = a * (k\rho c)^{-½} + b$$

Where:

$(k\rho c)^{-½}$ = inverse thermal inertia of material (cm^2 °C $sec^{½}$)/cal (Table 4-4: Inverse Thermal Inertia for Commonly Used Materials)

a, b = constants in Table 4-6: Cold Temperature Constants for Incidental Contact

2. For *intentional* contact, defined as planned skin contact for any length of time:

$$T_{PM}(°C) = a * (k\rho c)^{-½} + b$$

Where:

$(k\rho c)^{-½}$ = inverse thermal inertia of material (cm^2 °C $sec^{½}$)/cal (Table 4-4: Inverse Thermal Inertia for Commonly Used Materials)

a, b = constants in Table 4-7: Cold Temperature Constants for Intentional (Planned) Contact

Table 4-6: Cold Temperature Constants for Incidental Contact

time (s)	$(k\rho c)^{-½}$	a	b
1	≤ 43.5	-1.16	0
	> 43.5	-0.88	-12.29

Table 4-7: Cold Temperature Constants for Intentional (Planned) Contact

time (s)	a	b
10	-0.71	4.78
30	-0.62	9.51
60	-0.53	10.00
∞	-0.37	10.00
Note: for intentional contact, a minimum time of 10 seconds applies when calculating T_{PM}		

4.6.3 Electrical Hazards

V-HLS-S-HMTA-0226 Power Interruption

Statement: Analysis and Test. Crew interruption of electrical power and confirmation of energized circuits shall be verified by analysis and test. The analysis shall identify tasks and locations that could expose crewmembers to energized circuit. The test shall be in the flight vehicle and include a subject interrupting electrical power, checking the status and measuring the voltage at the locations identified in the analysis. Note: The verification for requirements HLS-S-HMTA-0226 and -0227 can be accomplished at the same time since each verification is needed to satisfy the other.

Verification Success Criteria: The analysis and test shall be considered successful when it is shown that the crewmember can interrupt electrical power, and confirm, within their fields of regard, the de- energized status of the circuit that could expose crewmembers and also verify the measured voltage indicates 0 volts.

V-HLS-S-HMTA-0227 Energized Status

Statement: Analysis and Test. Crew interruption of electrical power and confirmation of energized circuits shall be verified by analysis and test. The analysis shall identify tasks and locations that could expose crewmembers to energized circuit. The test shall be in

the flight vehicle and include a subject interrupting electrical power, checking the status and measuring the voltage at the locations identified in the analysis. Note: The verification for requirements HLS-S-HMTA-0226 and -0227 can be accomplished at the same time since each verification is needed to satisfy the other.

Verification Success Criteria: The analysis and test shall be considered successful when it is shown that the crewmember can interrupt electrical power, and confirm, within their fields of regard, the de- energized status of the circuit that could expose crewmembers and also verify the measured voltage indicates 0 volts.

V-HLS-S-HMTA-0228 Nominal Physiological Electrical Current Limits

Statement: Analysis and Test. Nominal Physiological Electrical Current Limits shall be verified by analysis and test. A task analysis shall be conducted that identifies exposed surfaces which could expose crew to electrical current. An analysis shall be conducted to verify that the identified surfaces comply with electrical isolation, grounding and bonding per HLS-STD-004. A test shall be conducted to measure the electrical current exposure level at the identified surfaces. The test shall be conducted with a body equivalent network (refer to IEC 60990, Figure 4, “Measuring network, touch current weighted perception or reaction”). For devices with enclosures made of insulating materials, IEC 60990 recommends using metal foil in contact with the enclosure for this test. The size of the foil is 10 cm x 20 cm to represent the human hand. Where adhesive metal foil is used, the adhesive will be conductive.

Verification Success Criteria: For direct current (DC), the verification shall be considered successful when analysis shows evidence of proper electrical isolation, grounding and bonding (per HLS-STD-004). Alternately, the verification shall be considered successful when current measurements on identified surfaces indicate the values meet the current limits stated in the requirement. For alternating current (AC), the verification shall be considered successful when current measurements on identified surfaces indicate the values meet the current limits stated in the requirement.

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

Statement: Analysis. Catastrophic Physiological Electrical Current Limits for all Circumstances shall be verified by analysis. The analysis shall define crew tasks which expose them to electrical current, and equipment analysis to determine the worst-case current values.

Verification Success Criteria: The verification shall be considered successful when analyses show the current values that the crew can be exposed to meet the limits stated in the requirement.

V-HLS-S-HMTA-0230 Physiological Electrical Current Limits for Startle Reaction Causing Catastrophic Condition

Statement: Analysis. Catastrophic Physiological Electrical Current Limits for Startle Reaction shall be verified by analysis. The analysis shall identify the operations that could result in catastrophic hazard due to startle reaction, and the equipment analysis to identify off-nominal situations where the current could exceed the values stated in the requirement.

Verification Success Criteria: The verification shall be considered successful when analyses show the current values meet the limits stated in the requirement or no operations result in a catastrophic hazard for startle reaction.

V-HLS-S-HMTA-0232 Leakage Currents – Medical and Bioinstrumentation Equipment

Statement: Analysis and Test. The patient-care equipment chassis leakage current requirement shall be verified by test and analysis. The test shall be conducted with a body equivalent network (refer to IEC 60990, Figure 4, “Measuring network, touch current weighted perception or reaction”). For devices with enclosures made of insulating materials, IEC 60990 recommends using metal foil in contact with the enclosure for this test. The size of the foil is 10 cm x 20 cm to represent the human hand. Where adhesive metal foil is used, the adhesive will be conductive. The analysis shall include equipment analysis to determine the current values based on the worst-case single failure.

Verification Success Criteria: The verification shall be considered successful when test and analysis results indicate the current values meet the current limits stated in the requirement.

4.6.4 Fluid Leak Hazards

V-HLS-S-HMTA-0234 Fluid Containment

Statement: Analysis. Protection of crew against release of fluids (liquids or gases) shall be verified through analysis. An analysis shall be performed to identify the hazard severity level of all fluids used in the system and the controls preventing their release.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that controls against release are commensurate with the hazard severity level during all operational phases.

4.6.5 Emergency and Protective Equipment

V-HLS-S-HMTA-0272 Emergency Equipment Accessibility

Statement: Analysis, Inspection, and Demonstration. The analysis shall identify and determine time to respond to emergency situations. Inspection shall confirm that emergency equipment is clearly identified. The demonstration shall be performed in a flight representative vehicle in flight configuration to show that a crewmember can

access emergency equipment and position it for use within a time commensurate with the applicable emergency.

Verification Success Criteria: The verification shall be considered successful when the analysis, inspection, and demonstration confirm that emergency equipment can be accessed for response to emergency situations within the time required to respond to the hazard.

V-HLS-S-HMTA-0260 Protective Equipment

Statement: Analysis and Inspection. The spacecraft's provision for PPE, including automated PPE, shall be verified through analysis and inspection. An analysis shall be performed to identify potential emergency scenarios and their designed control measures that include crew PPE. There shall be an inspection of PPE stowage locations.

Verification Success Criteria: The verification shall be considered successful when the analysis and inspection show that PPE is provided for each crewmember and is accessible by crew for potential emergency events.

V-HLS-S-HMTA-0261 Protective Equipment Use

Statement: Analysis and Test. The crew task analysis shall identify the nominal and contingency operations where crew will perform tasks while wearing protective equipment. The test shall utilize a flight configuration mockup with representative crew subjects in flight configuration performing select tasks, including communication, as agreed to through JTP, to evaluate task performance while wearing protective equipment.

Verification Success Criteria: The verification shall be considered successful when the test shows that the crew can successfully perform selected tasks, including communication among crew and operators, while wearing protective equipment.

V-HLS-S-HMTA-0263 Protective Equipment Automation

Statement: Analysis, Test, and Demonstration. The crew task analysis shall identify the scenarios where crew protective equipment is required and where crew may not be capable of activating the equipment (e.g., due to task workload, incapacitation, human error potential, or other task or health constraint). A Test shall utilize flight representative hardware and software to evaluate the performance of the automated solution to activate and operate protective equipment. When the integrated solution involves a response to crew action or inaction, the verification will involve HITL test and demonstration. A HITL test and demonstration shall utilize flight representative mockup/hardware and software in flight configuration(s) with representative subjects in flight configuration performing tasks involving crew protective equipment. The demonstration shall evaluate automation of the crew protective equipment and the ability of crew to perform complementary tasks.

Verification Success Criteria: The verification shall be considered successful when demonstration shows that Integrated Lander provides automated protective equipment when the crew may not be capable of activating the equipment.

V-HLS-S-HMTA-0266 Hearing Protection Interference

Statement: Test. Interference of hearing protection shall be verified through test. Tests shall be performed with operators who have hearing sensitivity that meets flight standards of NASA Crewmembers Medical Standards, Volume 1, without waiver as they wear hearing protection while performing representative in-flight operations with representative flight equipment in operation. Without prompting the operator, simulated alerts shall be triggered, and voice communications shall be conducted. The operator will indicate when alerts are heard or respond to voice communications.

Verification Success Criteria: The verification shall be considered successful when tests confirm that hearing protection does not inhibit voice communication or monitoring of the system or alerts.

4.6.6 Fire Detection and Response

V-HLS-S-HMTA-0267 Fire Suppression

Statement: Inspection and Analysis and/or Demonstration. The spacecraft's fire suppression for enclosed/isolated areas in the pressurized volume shall be verified by inspection and analysis and/or demonstration. An inspection shall be performed to show that fire suppression hardware is placed in enclosed/isolated areas in the pressurized volume where there are potential ignition sources combined with either forced air flow or credible oxygen enrichment/leakage that cannot be reached by crew using a PFE. An analysis and/or demonstration shall be performed to show that the fire suppression system is effective for suppressing credible fire sources and types and does not create any additional hazardous conditions for the crew. Additional hazards associated with use of fire suppression systems include, but are not limited to, asphyxiation, hypoxia, hypercapnia, or other inhalation hazards, generation of toxic products when extinguishant materials are exposed to elevated temperatures present during fire event, electrical shock hazards if extinguishant materials are electrically conductive, etc. The analysis shall consider the component qualification test data and the impacts of vehicle atmospheric pressure, oxygen concentration, and partial gravity on the spread and extinguishing of fires.

Verification Success Criteria: The verification shall be considered successful when the inspection shows that fire suppression is provided for enclosed/isolated areas in the pressurized volume with credible fire sources that cannot be reached by PFE; and when analysis and/or demonstration shows that the fire suppression system is effective for extinguishing credible fire sources and types without creating additional hazardous conditions for the crew.

V-HLS-S-HMTA-0268 Fire Protection System Health, and Status, and Failure Alerting

Statement: Analysis and Demonstration. The vehicles' requirement to display FPS health and status data to the crew and remote operators shall be verified by analysis and demonstration. The analysis shall identify the required health and status data sets needed and the timeliness required for the intended use in nominal operations, anomaly resolution, catastrophic event reconstruction, and commit to flight decision making. The demonstration shall confirm that required health and status data sets are provided to the crew and remote operators real-time.

Verification Success Criteria: The verification shall be considered successful when the demonstration confirms the required sets of generated health and status data are to the crew and remote operators real-time in support of nominal operations, flight anomaly resolution, catastrophic event reconstruction, and commit to flight decision making.

V-HLS-S-HMTA-0270 Fire Protection System Activation

Statement: Demonstration. The spacecraft's fire suppression system's ability to be automatically and manually activated and deactivated shall be verified by demonstration. A demonstration using flight software and flight-like command interfaces shall show that the fire protection system (including fixed fire suppression systems and FDIR actions to shut off air circulation, prevent cabin gas addition, etc.) can be turned on and off by crew command. The demonstration shall also show that the Integrated Lander initiates the proper actions (including vehicle-level FDIR actions and the activation of fixed fire suppression systems) in response to appropriate signals from the smoke detector(s).

Verification Success Criteria: The verification shall be considered successful when the demonstration shows the relevant systems are activated and deactivated by crew command and by Integrated Lander responses to signals from smoke detectors.

V-HLS-S-HMTA-0271 Portable Fire Extinguishers

Statement: Analysis and Inspection or Demonstration. The provisioning of manually operated portable fire extinguishers shall be verified by analysis and inspection or demonstration. An analysis shall be performed to identify the types and locations of potential ignition sources, suppression methods and amount of required suppressant for each, and placement of PFEs. This analysis shall consider the impacts of vehicle atmospheric pressure, oxygen concentration, and partial gravity on the spread and extinguishing of fires. The analysis shall show that fires can either be reached by the crew with a portable fire extinguisher or that the affected volumes have a fixed fire suppression system. The analysis must also show that the suppressant does not cause a hazardous condition such as asphyxiation, hypoxia, hypercapnia, or other inhalation hazards, generation of harmful products when extinguishant materials are exposed to elevated temperatures present during fire event, electrical shock hazards if extinguishant materials are electrically conductive, injury to the crewmember via PFE propulsive effects, PFE touch temperature violations, etc. . An inspection of drawings and models or a demonstration using a flight-like cabin layout shall confirm accessibility

of PFEs in their stowed locations, that any enclosed volume that needs fire suppression has a portable fire extinguisher access port to allow fire suppressant to be dispensed in it without having to open an access door/panel, and that the portable fire extinguisher has adequate clearance to interface with the portable fire extinguisher access port.

Verification Success Criteria: The verification shall be considered successful when the analysis shows a sufficient number of PFEs are available in the required locations to extinguish identified fires, the inspection or demonstration shows that manually operated portable fire extinguishers can access existing fire ports, analysis shows the portable fire extinguishers do not create additional hazards to the crew, and analysis and/or demonstration show the identified fires are fully suppressed using the PFE.

4.7 Design for Maintenance

V-HLS-S-HMTA-0237 Inflight Maintenance and Assembly

Statement: Inspection. Inspection of compliance with HLS-S-HMTA-0239, 0240, and 0241 including a mapping of VCNs, DRDs, Letters of Interpretation, and Variances.

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

V-HLS-S-HMTA-0246 In-Flight Tool Set

Statement: Analysis and Demonstration. The ability to perform maintenance activities shall be verified by analysis and demonstration. The crew task analysis shall identify maintenance and configuration tasks requiring the use of tools. A HITL demonstration shall be performed to ensure crew can perform maintenance and reconfiguration tasks using in-flight tools.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows crew can successfully perform maintenance and reconfiguration tasks using in-flight tool set.

V-HLS-S-HMTA-0247 Maintenance Time

Statement: Analysis and Test. The ability to complete planned maintenance tasks within planned crew task time shall be verified by crew task analysis and HITL test. Crew task analysis shall be performed to identify the maintenance tasks and performance times. The test shall utilize a flight configuration mockup with representative crew subjects in flight configuration performing select tasks, as agreed to through JTP, to evaluate planned maintenance performance time.

Verification Success Criteria: The verification shall be considered successful when the test shows that crew can successfully perform selected planned maintenance tasks within the planned time.

V-HLS-S-HMTA-0239 Connector Actuation without Tools

Statement: Demonstration. Connector Actuation without Tools shall be verified by demonstration.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows that all mating/de-mating connections are accessible and operable without the use of any tools.

V-HLS-S-HMTA-0240 Incorrect Mating, De-mating Prevention

Statement: Test. Incorrect mating and de-mating prevention shall be verified by test. The test shall use high-fidelity connectors in representative locations within the vehicle. The test shall consist of representative subjects, performing a representative set of mating/de-mating tasks. Any EVA connector mating/demating tasks shall involve NASA EVA community participation.

Verification Success Criteria: The verification shall be considered successful when the test has shown that representative tasks can be performed successfully by representative subjects.

V-HLS-S-HMTA-0241 Mating, De-mating Hazards

Statement: Analysis. The protection of crew from mate / de-mate hazards shall be verified through hazard analysis. An analysis shall be performed to identify mate / de-mate tasks, any associated exposure risks, and their design control measures.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that the crew is protected against hazardous fluid release, exposure to high energy sources, or other mate / de-mate hazards.

V-HLS-S-HMTA-0242 Cable and Hose Management

Statement: Demonstration and Inspection. Inspection shall consist of inspection of drawings related to cable management, and operational configurations. Demonstration shall consist of dynamic cable and hose movement (e.g. vacuum cleaner, umbilicals).

Verification Success Criteria: The verification shall be considered successful when inspection shows cable management, and operational configurations. Demonstration shall be considered successful when cables and hoses can be managed and do not interfere with operational tasks.

V-HLS-S-HMTA-0243 Cable and Hose Identification

Statement: Inspection. Inspection shall consist of inspection of label and cable drawings and labeling plan.

Verification Success Criteria: The verification shall be considered successful when inspection shows that all maintainable hoses and cables are identified.

V-HLS-S-HMTA-0254 Maintenance Accommodation

Statement: Analysis and Demonstration. The ability to perform maintenance activities shall be verified by analysis and demonstration. The crew task analysis shall identify required tools, and any protective equipment needed to perform maintenance. A HITL demonstration shall be performed to ensure crew can access and has accommodation to complete maintenance using tools and protective equipment.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows crew can successfully access and has proper accommodation to complete maintenance using tools and protective equipment.

V-HLS-S-HMTA-0255 Visual Access for Maintenance

Statement: Analysis and Demonstration. Visual access for maintenance activities shall be verified by analysis and demonstration. The crew task analysis shall identify required task which require visual feedback. A HITL demonstration shall be performed to ensure crew has direct visual feedback during task performance.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows crew as direct visual feedback during task performances.

V-HLS-S-HMTA-0257 Tool Clearance

Statement: Analysis and Demonstration. Tool clearance for in-flight maintenance activities shall be verified by analysis and demonstration. The crew task analysis shall identify required tasks which require the use of tools and the clearance needed. A HITL demonstration shall be performed to ensure crew has tool clearance during in-flight maintenance.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows crew members have tool clearances for tool installation and actuation for all tool interfaces during in-flight maintenance.

4.8 Crew Interface Design

4.8.1 Design for Crew Performance

V-HLS-S-HMTA-0273 Operability and Usability

Statement: Inspection and Test. Operability and usability shall be verified by inspection of crew task analysis and HITL test of select tasks for operability, usability, and performance times per crew task analysis. A minimum of 10 trained participants shall perform representative onboard tasks, identified through crew task analysis, in a high-fidelity, flight representative mockup or simulator. Usability evaluations should include collection of data such as completion times and ratings on subjective questionnaires that will help identify task or interface design or procedure problems. For the usability evaluation, a task is defined as an activity driven by a procedure. The procedure consists of a series of task steps, where a task step is defined as a single instruction to

the crewmember, as is typical of current spaceflight procedures. Each task must be completed; failed or incomplete tasks do not pass verification. Participants should maintain task completion times commensurate with the performance requirements of the particular task. The NASA Modified System Usability Scale should be completed by test participants at the conclusion of each selected task scenario, and prior to any debrief or administering of post-evaluation questionnaires.

Verification Success Criteria: Verification shall be considered successful when the HITL test shows that selected tasks are successfully performed within task times as defined by crew task analysis and have an average score on the NASA Modified SUS of 85 or above.

V-HLS-S-HMTA-0490 Operable by Single Crew

Statement: Analysis and Test. Operable by Single Crewmember - shall be verified by Analysis and Test. Test via human-in-the-loop test (HITL). An operational crew task analysis shall be completed to ensure all accommodations for single crew operability have been considered in the design phase. HITL tests shall be driven by the crew task analysis results and performed in flight representative mockups with crewmembers or crew designated representatives in the appropriate configuration for the mission and phase (suited or unsuited, helmet, gloves, restraints, tools, etc.). The objective is to verify that a single crewmember can accomplish all necessary piloting, crew systems, and other vehicle tasks requiring crew control. A minimum of ten (10) crew or crew designated representatives shall be used for each HITL test.

Verification Success Criteria: The verification shall be considered successful when the analysis and test show that the Integrated Lander is operable, and tasks can be successfully completed by any single crewmember for operations requiring crew control.

V-HLS-S-HMTA-0501 Operable by Single Crewmember Redundancy

Statement: Analysis and Test. Redundancy in spacecraft operability by a single crewmember through safe, rapid, and seamless transitions in responsibilities between Commander and Pilot shall be verified by analysis and human-in-the-loop (HITL) test. An operational crew task analysis shall be completed to ensure all accommodations for planned contingencies have been considered in the design phase. HITL tests shall be driven by the crew task analysis results and performed in flight representative mockups with crewmembers or crew designated representatives in the appropriate configuration for the mission and phase (suited or unsuited, helmet, gloves, restraints, tools, etc.). The objective is to verify that a single crewmember can accomplish all necessary tasks requiring crew control, and that transitions in responsibilities between the Commander and Pilot are rapid and seamless. A minimum of ten (10) crew or crew designated representatives shall be used for each HITL test.

Verification Success Criteria: The verification shall be considered successful when the analysis and tests show that the Integrated Lander enables safe, rapid, and seamless

transitions in responsibilities between the Commander and Pilot and that all necessary tasks requiring crew control are accomplished by a single crewmember.

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

Statement: Analysis and Test. Handling qualities shall be verified by analysis and test. Selected, NASA-approved manual control scenarios will be defined via review of potential manual control scenarios and associated manual control modes. Analysis shall be performed to select the manual control scenarios selected for testing and required handling qualities ratings. Manual control scenarios shall be selected based on the following considerations: 1) manual control scenarios necessary to meet Manual Piloting for Docking, 2) catastrophic hazard controls that utilize manual control capabilities as part of their mitigation strategy, and 3) manual control scenarios that are uniquely different or more complex than Manual Piloting for Docking. For each selected scenario, a list of handling quality related tasks will be generated as part of a crew task analysis. A handling quality related task is defined as the manual control capability that is being rated with the Cooper-Harper Rating Scale. Each task within a scenario is rated separately and must meet Level 1 (handling quality ratings of 1, 2, or 3). A test shall be conducted for each selected scenario with at least five test subjects trained as pilots for the particular spacecraft being evaluated and trained in Cooper-Harper evaluations. Test subjects shall perform the manual control scenarios in flight configuration using flight representative cockpit hardware and software and provide Cooper-Harper evaluations for each task in the scenario.

Verification Success Criteria: The verification shall be considered successful when the analysis and test show that for each task associated with each of the manual control scenarios where manual control is the selected control method or where the automated control system is non-operational, at least 60% of the ratings are Level 1 (handling quality ratings of 1, 2 or 3), while up to 40% may exceed Level 1 with a Level 2 rating (handling quality rating of 4, 5, or 6). For any ratings of 4, 5, or 6 to be considered successful, a consensus must be reached by all of the participants indicating that handling qualities are acceptable. For all other scenarios, at least 80% of the ratings must be Level 1 or 2 (HQR of 1, 2, 3, 4, 5 or 6), while up to 20% may exceed Level 2 with a Level 3 rating (HQR of 7, 8 or 9). For any ratings of 7, 8, or 9 to be considered successful, a consensus must be reached by all of the participants indicating that handling qualities are acceptable.

V-HLS-S-HMTA-0304 Design Induced Crew Error

Statement: Inspection and Test. Design induced error shall be verified by inspection of crew task analysis and HITL test of select task scenarios. The HITL test shall include a minimum of 10 crewmembers or crew designated representatives that will perform a set of NASA-approved onboard tasks in a high-fidelity flight-like simulator or mockup. HITL test should include collection of data such as completion times and ratings on subjective questionnaires that will help differentiate design-induced errors from errors related to human reliability. A task is defined as an activity driven by a procedure. The procedure consists of a series of task steps, where a task step is defined as a single instruction to

the crewmember, as is typical of current spaceflight procedures. Each task must be completed; failed or incomplete tasks do not pass verification. Participants should maintain task completion times commensurate with the performance requirements of the particular task. The percentage of erroneous task steps for each participant is calculated by dividing the number of erroneous task steps and incomplete task steps by the total number of task steps in that scenario and multiplying the result by 100. The percentage of participants committing each erroneous task step is calculated by dividing the number of participants committing each erroneous task step by the total number of participants and multiplying the result by 100.

Although errors are often calculated as averages across participants, the approach used in this verification (calculating errors per participant and per task step) ensures that the number of design-induced errors of every task step and every participant is minimized. The approach puts the emphasis on identifying usability problems, rather than just calculating an overall error rate. When more than 10% of participants commit the same erroneous task step, this indicates a serious design issue. When one or more participants commit more than 5% erroneous task steps across the task, this again could indicate serious design issues. If a single participant commits more than 5% erroneous task steps, this could indicate an issue such as deficiency in training or fatigue. In this case, results should be discussed with NASA. Usability verification can be accomplished along with other verifications in well-planned human-in-the-loop evaluations.

Verification Success Criteria: The verification shall be considered successful when the results of the HITL test show that the percentage of erroneous task steps per participant per scenario is no greater than 5%, and the percentage of participants who committed each erroneous task step is no greater than 10%.

V-HLS-S-HMTA-0300 Tolerate Inadvertent Operator Action

Statement: Analysis and Demonstration. A crew task and human error potential analysis shall be performed to identify human interactions required for the operation and control of the system, including responses to system failures, and the potential sources and consequences of human error. A hazard analysis using inputs from human error analysis shall be performed to identify the hardware, software, and operational controls to tolerate inadvertent activation of command or control functions. A demonstration of select crew tasks shall be performed utilizing flight representative hardware and software to assess the system response to simulated inadvertent operation and accidental changes in system status. Verification of HMTA-0300 should be performed in conjunction with SMA-0005 Mitigate Hazardous Software Behavior.

Verification Success Criteria: Verification shall be considered successful when the analysis and demonstration show that the system tolerates inadvertent operator action, including in the presence of any single system failure.

V-HLS-S-HMTA-0301 Inadvertent Operation Prevention

Statement: Analysis, Inspection, and Demonstration. Inadvertent operation shall be verified by analysis, inspection and demonstration. An analysis shall identify controls whose inadvertent operation would lead to a catastrophic event or an abort and the appropriate level of protection (i.e. one, two, or more inadvertent actions) required. The analysis shall include all mission phases, including operations planned for response to system failures. The inspection and the demonstration shall be performed using flight-configuration hardware and software. The demonstration shall simulate inadvertent inputs using flight representative hardware and software.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows an “arm-fire” mechanism or action confirmation for commands using a computer display and when the inspection documents the presence of effective guards, covers, and physical separation from other controls.

V-HLS-S-HMTA-0302 Inadvertent Operation Recovery

Statement: Analysis and Demonstration. Inadvertent operation recovery shall be verified by analysis and demonstration. A crew task and human error potential analysis shall be performed to identify human interactions required for the maintenance, operation, and control of the system, and the potential sources and consequences of human error. A hazard analysis using inputs from human error analysis shall be performed to identify the hardware, software, and operational controls to mitigate and recover from inadvertent activation of control functions. A demonstration of select human system interaction tasks shall be performed utilizing flight representative hardware and software to assess the system response to simulated inadvertent operation and accidental changes in system status. Verification of HMTA-0302 should be performed in conjunction with SMA-0005 Mitigate Hazardous Software Behavior.

Verification Success Criteria: The verification shall be considered successful when the analysis and demonstration show that the control systems allow for recovery from inadvertent operation and accidental changes in system status.

V-HLS-S-HMTA-0303 Control for Human Error

Statement: Analysis, Inspection, and Demonstration. The Integrated Lander implementation of human error controls shall be verified by analysis, inspection, and demonstration. A crew task analysis shall be performed to identify human interactions required for the maintenance, operations and control of the system. A human error analysis (HEA) shall be performed, as defined in NPR 8705.2C, Section 2.3.11 Human Error Analysis. The HEA shall define the source of human errors derived from the tasks, the consequence on the system, and the design and operational controls to mitigate or limit the effects. An inspection of drawings and hardware shall confirm maintenance and operational controls for human error have been incorporated. A demonstration of human system interaction tasks shall be performed with simulated errors utilizing flight representative hardware and software.

Verification Success Criteria: The verification shall be considered successful when the human error analysis defines the source of human errors derived from the tasks and the design and operational controls to mitigate or limit their effects; the inspection shows that design and operational controls have been implemented for those sources of errors identified in the HEA; the demonstration shows that the mitigation identified in the HEA is effective at preventing the error or, when prevention is not appropriate, reduces the error's likelihood and impact by allowing the human to detect and correct or recover from the errors; and the inspection of engineering processes reflect the error mitigation precedence, as applicable.

V-HLS-S-HMTA-0305 Crew Control of Vehicle

Statement: Inspection and Test. Crew control of vehicle shall be verified by inspection of failure modes and effects analysis (FMEA), hazard analyses, and crew task analysis; and HITL demonstration of select crew tasks.

Verification Success Criteria: The verification shall be considered successful when inspection confirms that crew tasks have been planned for capabilities necessary to execute the mission, prevent catastrophic events, and prevent aborts; and when HITL demonstration of select crew tasks shows that crew are able to perform those tasks per HLS-S-HMTA-0273 Operability and Usability and HLS-S-HMTA-0012 Nominal Cognitive Workload.

4.8.2 Design Standardization and Consistency

V-HLS-S-HMTA-0278 Operations Nomenclature Standardization

Statement: Inspection. Integrated Lander use of operations nomenclature (OpNom) shall be verified by inspection of crew interface items and crew procedures to assess the use of jointly-agreed OpNom that are documented in the Artemis Operations Nomenclature Database. The effectiveness of OpNom implementation will be verified further in V-HLS-S-HMTA-0273 and HMTA-0304.

Verification Success Criteria: The verification shall be considered successful when inspection shows the Integrated Lander has used operations nomenclature as documented in the Artemis Operations Nomenclature Database for Integrated Lander crew interfaces including the displays, labeling, and procedures.

V-HLS-S-HMTA-0279 Graphical User Interface Display Standards

Statement: Inspection. Graphical User Interfaces shall be verified by inspection of GUI displays and consistency checklist per HLS-STD-002 HLS Program GUI Standard. The effectiveness of GUI displays will be verified in HMTA-0273 and HMTA-0304.

Verification Success Criteria: The verification shall be considered successful when inspection shows that GUI displays are consistent with the HLS-STD-002 HLS Program GUI Standard.

V-HLS-S-HMTA-0280 Units of Measure

Statement: Inspection. The use of units of measurement shall be verified through inspection. A sample of drawings (e.g., vehicle and workstation labeling), mission software applications, and operational procedures shall be inspected to verify that the same units of measurement are used.

Verification Success Criteria: Verification shall be considered successful when the use of units of measurement are the same across like items.

V-HLS-S-HMTA-0286 Syntax Distinction

Statement: Analysis and Test. Syntax distinction shall be verified by analysis and test. A crew task analysis shall identify a representative set of commands that need to be distinguished to preclude issuing an unintended command. The HITL test shall be driven by the crew task analysis results and performed in flight representative simulator or mockup with crewmembers and other crew designated representatives and can be part of an integrated test in conjunction with HLS-S-HMTA-0273, HLS-S-HMTA-0304, and HLS-S-HMTA-0343.

Verification Success Criteria: The verification shall be considered successful when the analysis identifies a representative set of commands that need to be distinguished, and the HITL test show that subjects can distinguish commands to operate the system as intended. This assessment can be combined with verification activities for HLS-S-HMTA-0273 Operability and Usability, HLS-S-HMTA-0304 Design Induced Crew Error, and HLS-S-HMTA-0343 Visual Display and Label Legibility.

4.8.3 Human and System Interaction

V-HLS-S-HMTA-0289 System Health and Status

Statement: Demonstration. System Health and Status shall be verified by demonstration. Demonstration shall include simulating a variety of system and component health conditions including nominal and off-nominal.

Verification Success Criteria: The demonstration shall be considered successful when system health and status is available for crew and Mission Systems viewing and it accurately represents the system and component health states established in the simulation.

V-HLS-S-HMTA-0293 Control Feedback

Statement: Demonstration. Feedback of crew-initiated control activation shall be verified by demonstration. The demonstration shall consist of simulating crew activation of flight-configuration hardware and software controls.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows that all control systems provide an indication of crew-initiated control activations.

V-HLS-S-HMTA-0294 System Response Time to Crew Input
Statement: Test. System Response Time shall be verified by Test. The test shall measure the system response time to crew input.

Verification Success Criteria: The test shall be considered successful when system response time meets the criteria of HLS-RQMT-006, Table C-23: Maximum System Response Time To Crew Input.

V-HLS-S-HMTA-0498 Missing Data
Statement: Demonstration. Properly coded missing data shall be verified by demonstration. A high-fidelity system simulator shall run a simulation with selected telemetry values turned off/not transmitting.

Verification Success Criteria: The verification shall be considered successful when missing data are shown on display systems.

4.8.4 Electronic Procedures

V-HLS-S-HMTA-0295 Electronic Procedures
Statement: Demonstration. Onboard electronic procedures shall be verified by demonstration. The demonstration shall take place in an integrated vehicle system.

Verification Success Criteria: Verification shall be considered successful when the demonstration shows that the system allows the crew to accurately and efficiently view current, completed, and future procedure steps.

4.8.5 Design of Controls

V-HLS-S-HMTA-0307 Control Identification
Statement: Demonstration and Analysis. Distinguishability of critical out -of -view commanding shall be verified by demonstration and analysis. Analysis shall be performed to determine any out-of-view controls that affect critical vehicle operation that, if inadvertently commanded, may result in danger to crew. Analysis shall also identify the flight phases and crew configurations (suited, pressurized) that crew may experience in operating the controls. Demonstration by HITL demonstration shall consist of participants in their flight-like configurations per the analysis using the out-of-view controls for a selected set of assigned control tasks.

Verification Success Criteria: The verification shall be considered successful when the analysis identifies out-of-view controls with vehicle critical commanding functionality. Additionally, the HITL demonstration shall be successful when the crew are able to distinguish and operate out of view controls.

V-HLS-S-HMTA-0308 Emergency Control Coding

Statement: Analysis, Inspection or Demonstration. Distinguishability of emergency controls from non-emergency controls shall be verified by demonstration, inspection and analysis. Analysis shall be performed to identify emergency controls. Demonstration by HITL demonstration shall consist of participants in their flight-like configurations per the analysis using the emergency controls for a selected set of assigned control tasks. Inspection of drawings or labeling plan shall be performed to confirm emergency control coding is distinguishable from non-emergency controls.

Verification Success Criteria: The verification shall be considered successful when the analysis identifies emergency and non-emergency controls. The HITL demonstration shall be successful when the crew are able to distinguish and operate emergency controls. Inspection shall be considered successful when emergency control coding is distinguishable from non-emergency controls.

V-HLS-S-HMTA-0312 Control Operation during Accelerations

Statement: Analysis and Test. Control Operation during Accelerations shall be verified by analysis and test. Test shall be performed in simulated flight-like environment (e.g., human centrifuge) with crew performing tasks expected to occur acceleration and vibration conditions. Crew task analysis shall identify crew tasks under the acceleration, vibration and micro-gravity environments.

Verification Success Criteria: The verification shall be considered successful when the test shows crew are able to successfully perform tasks under flight-like acceleration and vibration environments.

V-HLS-S-HMTA-0314 Control Input-Response Compatibility

Statement: Demonstration. The verification shall be considered successful when the demonstration shows that controls are designed so that input direction is compatible with the resulting control and display response, as defined in Table 4-8: Input-Output Compatibility.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows that controls are designed so that input direction is compatible with the resulting control and display response, as defined in Table 4-8: Input-Output Compatibility.

Table 4-8: Input-Output Compatibility

Device		Direction of Movement and Result
Knobs	Continuous and discrete position rotary	• Turn clockwise with hand or fingers – turn function on, increase value, move discrete cursor right, move displayed page left

Table 4-8: Input-Output Compatibility

Device		Direction of Movement and Result
		• Turn counterclockwise with hand or fingers – turn function off, decrease value, move discrete cursor left, move displayed page right
	Ganged	• Turn each individual knob clockwise with hand or fingers – turn function on, increase value, move discrete cursor right, move displayed page left • Turn each individual knob counterclockwise with hand or fingers – turn function off, decrease value, move discrete cursor left, move displayed page right
Thumbwheels or scroll wheels (operated by brushing/ turning the edge of the wheel):	Vertical wheel orientation	• Move thumbwheel/scroll wheel edge forward with thumb or finger – turn function on, increase value, move a discrete cursor up, move displayed page down • Move thumbwheel/scroll wheel edge backward with thumb or finger – turn function off, decrease value, move a discrete cursor down, move displayed page up
	Horizontal wheel orientation	• Move thumbwheel/scroll wheel edge right with thumb or finger – turn function on, increase value, move a discrete cursor right, move displayed page left • Move thumbwheel/scroll wheel edge left with thumb or finger – turn function off, decrease value, move a discrete cursor left, move displayed page right
	Handwheels (operated by grasping the wheel's perimeter and turning) Note: Excludes valve wheels	• Rotate handwheel clockwise with hand – turn function on, increase the value, move discrete cursor right, move displayed page left • Rotate handwheel counterclockwise with hand – turn function off, decrease value, move discrete cursor left, move displayed page right
	Pedals	• Apply pressure to pedal with foot – turn function on, engage action, increase value. • Reduce pressure to pedal with foot – turn function off, disengage action, decrease value
Push-Pull Controls	Momentary Push Buttons	• Press and release to activate object or select menu item Press to activate function; release to deactivate function
	Push-pull controls	• Pull control with hand – turn function on Push control with hand – turn function off

Table 4-8: Input-Output Compatibility

Device		Direction of Movement and Result
Rocker Switches	Vertical rocker orientation	• Depress upper wing with finger – turn function on, increase value, move discrete cursor up, move displayed page down • Depress lower wing with finger – turn function off, decrease value, move discrete cursor down, move displayed page down
	Horizontal rocker orientation	• Depress right wing with finger – turn function on, increase value, move discrete cursor right, move displayed page left • Depress left wing with finger – turn function off, decrease value, move discrete cursor left, move displayed page right
Slide/Toggle Switches	Vertical switch orientation	• Slide/flip switch forward with fingers – turn function on or increase value • Slide/flip switch backward with fingers – turn function off or decrease value
	Horizontal switch orientation	• Slide/flip switch right with fingers – turn function on or increase value Slide/flip switch left with fingers – turn function off or decrease value
Cursor Control	Continuous cursor control devices (joystick, mouse, trackball, etc.)	• Move device forward with hand – cursor moves up, displayed page moves down • Move device backward with hand – cursor moves down, displayed page moves up • Move device left with hand – cursor moves left, displayed page moves right • Move device right with hand – cursor moves right, displayed page moves left • Move device diagonally with hand in any direction – cursor moves diagonally in the same direction as the device's movement, displayed page moves diagonally opposite
	Discrete cursor control devices (arrow keys, castle switches)	• Press/deflect up key, switch, or button with finger – cursor moves up, displayed page moves down • Press/deflect down key, switch, or button with finger – cursor moves down, displayed page moves up • Press/deflect right key, switch, or button with finger – cursor moves right, displayed page moves left • Press/deflect left key, switch, or button with finger – cursor moves left, displayed page moves right

Table 4-8: Input-Output Compatibility

Device		Direction of Movement and Result
		• (If diagonal capability exists) Press/deflect key, switch, or button diagonally with hand in any direction – cursor moves diagonally in the same direction as the device's movement; displayed page moves diagonally opposite
Hand Controller	Rotational Hand Controller (RHC)	• Pivot controller forward – pitch vehicle down Pivot controller backward – pitch vehicle up Pivot controller right – roll vehicle right • Pivot controller left – roll vehicle left • Rotate control clockwise with hand – yaw vehicle right Rotate control counterclockwise with hand – yaw vehicle left
	Translational Hand Controller (THC)	• Push in on control with hand – move vehicle forward Pull out on control with hand – move vehicle backward • Push right on control with hand –move vehicle to the right Push left on control with hand – move vehicle to the left Push up on the control with hand – move vehicle up • Push down on the control with hand – move vehicle down

NOTE: Movement directions are from the user's nominal perspective. When a control affects a cursor or an indicator on an electronic display, the control/display relationship of up and down movements may be dependent on the angle of the control mounting (with respect to the body and display) or on the prior experience of the user. The information in the table above assumes that the control is mounted in the horizontal plane and the display is in the vertical plane at roughly 90° to the body. Usability testing may be necessary to confirm the best mapping.

V-HLS-S-HMTA-0315 Control Latency

Statement: Analysis and Test. Control latency shall be verified by analysis and test. Analysis shall be used to assess the control latency prior to testing, providing evidence that control latency is within the acceptable limits of less than 100ms for high gain tasks and less than 200 ms for low gain tasks. Definition of low gain and high gain tasks shall be made with programmatic agreement from the list of manual control scenarios and tasks used in the verification of handling qualities for manual control (V-HLS-S-HMTA-0299). Tests using selected manual control scenarios and associated tasks shall be conducted with at least five (5) test subjects trained as pilots for the particular spacecraft being evaluated and trained in Cooper-Harper evaluations. The test shall assess acceptability of the latency and latency variability as impacts on vehicle handling qualities. Test subjects shall perform the manual control scenarios in flight configuration in a flight representative cockpit and provide acceptability ratings of control latency in conjunction with Cooper-Harper ratings for each task in the scenario. This test can be combined with the test used to verify handling qualities for manual control (V-HLS-S-HMTA-0299). Acceptability ratings will be on a 10-point scale, with verification criteria

acceptance requiring an average score across the test subjects of 8/10 or higher for each scenario and task. Control latencies that exceed a delay of 100 milliseconds for high-gain and 200 milliseconds for low-gain tasks shall be verified per V-HLS-S-HMTA-0299.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that control latency is within the acceptable limits of less than 100ms for high gain tasks and less than 200 ms for low gain tasks, and when testing provides evidence of acceptability of the latency and its variability in the form of acceptability ratings that test subjects consider the control latency acceptable with an average score across the test subjects of 8/10 or higher for each scenarios and tasks. If latency is greater than 100 milliseconds for high-gain or 200 milliseconds for low-gain tasks, the longer latency time shall meet HLS-S-HMTA-0299 Controllability and Maneuverability (Manual Control).

V-HLS-S-HMTA-0499 Display System Latency for Piloting

Statement: Analysis and Test. Display latency between the change in vehicle dynamics and the representation of associated new information on the display shall be verified by analysis of the high fidelity/ flight-equivalent integrated, hardware/software system, supported by test. Test generated data used by the analysis shall include participating avionics system component certification data. Analysis shall be used to confirm that display system latency is within acceptable limits (i.e., less than 50 milliseconds) for piloting displays. Display latencies that exceed a delay of 50 milliseconds shall be verified per V-HLS-S-HMTA-0299.

Verification Success Criteria: The verification shall be considered successful when the analysis and test shows that display system lag does not exceed a delay of 50 milliseconds. If latency is greater than 50 milliseconds, the longer latency time shall meet HLS-S-HMTA-0299 Controllability and Maneuverability (Manual Control).

V-HLS-S-HMTA-0316 Control Resistive Force

Statement: Demonstration. Control resistive force shall be verified by demonstration. A demonstration shall show that controls are designed to withstand (a) planned vehicle orientations and accelerations, and (b) resting and casual hand contract without unintended activation. Use of high fidelity or flight system shall be used in the demonstration.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows that controls are designed so that unintended activation does not occur under these conditions and that deliberate control is required for actuation.

V-HLS-S-HMTA-0319 Command Confirmation

Statement: Analysis and Demonstration. Command Confirmation shall be verified by analysis and HITL demonstration. Functional and crew task analysis shall identify the list of critical, hazardous and destructive commands that are allocated to crew control.

HITL demonstration shall utilize the results of the analysis and flight representative mockup/hardware in flight configuration with representative crew subjects in flight configuration performing select tasks, as agreed to through JTP, to show positive and negative confirmation and the absence of confirmation result in correct system response in each case.

Verification Success Criteria: The verification shall be considered successful when the analysis and demonstration show that the identified critical, hazardous, and destructive commands require crew confirmation and that the system responds correctly to each case of positive, negative, and absence of confirmation.

4.8.6 Design of Displays

V-HLS-S-HMTA-0334 Display Area

Statement: Analysis and Demonstration. Display Area shall be verified by scenario and crew task analysis and HITL demonstration. Analysis shall identify the display information required for crew control of critical tasks. HITL demonstration shall utilize the results of the analysis and flight representative mockup/hardware in flight configuration with representative crew subjects in flight configuration performing select tasks, as agreed to through JTP, to show that the display area and displayed information provides necessary information for crew to perform critical tasks accurately (HLS-S-HMTA-0304), within defined task time, and with average satisfaction score of 85 or higher HLS-S-HMTA-0012, 0013, 0273) without scrolling or switching among display pages and without excessive head or body movement by the crewmember to view multiple displays.

Verification Success Criteria: The verification shall be considered successful when the analysis and demonstration show the display area and associated display information provide necessary information for crew to perform critical tasks accurately, within defined task time, and with average satisfaction score of 85 or higher without scrolling or switching among display pages and without excessive head or body movement by the crewmember to view multiple displays.

V-HLS-S-HMTA-0341 Display Coding Redundancy

Statement: Inspection. Display Coding Redundancy shall be verified by inspection. Inspection shall include the review of drawings that show use of color coding and alternate coding.

Verification Success Criteria: The verification shall be considered successful when the inspection shows that additional cues are provided when color is used to convey meaning.

V-HLS-S-HMTA-0342 Measurement Units

Statement: Inspection. Presentation of measurement units associated with datum and groups of data shall be verified by inspection of display formats or display standards.

Verification Success Criteria: The verification shall be considered successful when the inspection shows units of measure are displayed with their corresponding values.

V-HLS-S-HMTA-0343 Visual Display and Label Legibility

Statement: Analysis and Test. Legibility shall be verified by Analysis and Test. A crew task analysis shall identify a representative set of text and graphic elements that need to be read and interpreted, and the correlating vehicle conditions and environments. The test shall consist of a HITL test with a minimum of ten crew-like participants in a flight representative vehicle in the flight configuration. The legibility test shall consist of verbal identification by subjects of a representative selection of targets such as hardware labels and software elements (alphanumeric, icons, and symbols)**.**

Verification Success Criteria: The verification shall be considered successful when the HITL test shows that all display and label elements for all representative tasks can be read with 100% accuracy, with no participant comments about difficulty due to confusable elements. This assessment can be combined with verification activities for HLS-S-HMTA-0273 Operability and Usability.

4.8.7 Design for Information Management

V-HLS-S-HMTA-0350 Information Management Capabilities – Provision

Statement: Analysis and Test. Information management capabilities shall be verified by analysis and test. Crew task analysis shall identify data and procedural flow of information needed by crew for mission planning, mission operations, system maintenance, and system health and status checks. test shall consist of usability (HLS-S-HMTA-0273), effectiveness, and design induced error (HLS-S-HMTA-0304) evaluations with a minimum of 10 crewmembers or crew designated representatives performing a set of NASA-approved tasks. This analysis and test shall encompass Information displays include electronic and non-electronic media (e.g., fixed or mobile electronic displays, labels, procedures, placards).

Verification Success Criteria: The verification shall be considered successful when analysis and test show that the system information management and information displays (electronic and non-electronic) support the crew in performing mission planning, mission operations, system maintenance, and system health and status checks with satisfactory usability and within acceptable error limits and scheduled operating times.

V-HLS-S-HMTA-0360 Information Backup and Restoration

Statement: Demonstration. Information Backup and Restoration shall be verified by demonstration. The demonstration shall be performed using flight-like software and high-fidelity crew interfaces with actual or simulated failures as applicable.

Verification Success Criteria: The verification shall be considered successful when demonstration shows that crewmembers can manually restore essential functions back to a safe state when automated recovery is not provided and that operationally relevant information is preserved.

V-HLS-S-HMTA-0361 Alternative Information Sources

Statement: Demonstration. Demonstration shall be performed to confirm that the information management system provides alternative information sources appropriate to the task for use in the event of the loss of the information management system.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows that alternative information sources are sufficient to perform safety critical tasks and/or restore the information management system to a safe state.

V-HLS-S-HMTA-0362 Software System Recovery

Statement: Analysis and Test. Software System Recovery shall be verified by analysis & test. Analysis shall determine the definition of “safe state” and required time for system recovery under representative scenario conditions, and a test shall be performed to reset the information management system and measure the time until the system is recovered to a safe state.

Verification Success Criteria: The verification shall be considered successful when test shows the system can recover from a software system crash to the safe state within the required time as determined by analysis.

4.8.8 Design for Communication

V-HLS-S-HMTA-0363 Communication System Design

Statement: Demonstration. Demonstration shall show how users can configure individual voice channels for all combinations of communications endpoints, as well as configuring for shared crew communications to all relevant combinations of endpoints.

Verification Success Criteria: The verification shall be considered successful when demonstration shows users can configure individual voice channels for all combinations of communications endpoints, as well as configuring for shared crew communications to all relevant combinations of endpoints.

V-HLS-S-HMTA-0500 Voice Channel Conferencing

Statement: Demonstration and Test. Voice Channel Conferencing shall be verified through demonstration and test. Demonstration shall be performed by use of flight-like fidelity models verifying capability to select four independent or simultaneous audio conferences at each crew wired and wireless audio communication station. Test shall be performed to ensure no coupling between audio conferences.

Verification Success Criteria: The verification shall be considered successful when a demonstration and test shows that crew members can select and configure four simultaneous audio conferences at each crew wired and wireless audio communication station with no coupling between audio conferences.

V-HLS-S-HMTA-0371 Speech Intelligibility

Statement: Analysis and Test. Speech Intelligibility shall be verified by test and analysis. Analysis shall derive the nominal background noise spectrum for testing. The test shall be made with a flight representative vehicle in the flight configuration using the methodology given in ANSI S3.2-2009.

Verification Success Criteria: The verification shall be considered successful when the test and analysis indicates a 90% word identification rate at the ear of the listener throughout the habitable volume with expected ambient noise levels.

V-HLS-S-HMTA-0372 Private Audio and Video Communication

Statement: Analysis, Inspection, and Demonstration. The provision for ensured privacy of all crew health and medical data shall be verified by analysis and inspection. The analysis shall assess the collection, transmission and storage of medical data. The inspection shall review the command and control architecture against the unintentional access and distribution of crew medical and personal data. Flight-like avionics shall be used to perform an integrated demonstration of audio and video communications between the Integrated Lander and the physician positions at Mission Control Center (MCC).

Verification Success Criteria: The verification shall be considered successful when the analysis and inspection show that the ground command and control architecture ensures the secure collection, transmission, storage and access to private audio and video data; and the demonstration shows the audio and video transmitted between the vehicle and the Mission Control Center can only be heard and viewed in the vehicle and at the designated flight control team positions.

4.8.9 Design of Alerts

V-HLS-S-HMTA-0379 Alert Annunciation

Statement: Demonstration and Test. Alert Annunciations shall be verified by demonstration and test. A demonstration shall be performed on all audio annunciations and visual indications using a flight-configuration system to annunciate the signals. During the demonstration, signal content will be compared to HLS-RQMT-006, Table C-27: Alert Annunciation, as well as the ability to manage alerts. HITL test shall be performed using a flight configuration system to present scenarios with representative combinations of possible alerts to measure test subjects' perceived cognitive workload.

Verification Success Criteria: Verification shall be considered successful when the demonstration shows that all audio annunciations and visual indications meet the HLS-

RQMT-006, Table C-27: Alert Annunciation and the HITL test shows that alerts can be managed resulting in acceptable cognitive workload per HLS-S-HMTA-0012 and HMTA-0013.

V-HLS-S-HMTA-0508 Alert Suppression and Inhibits

Statement: Demonstration. The crew capability to suppress and inhibit alerts shall be verified by demonstration of flight representative simulation of alerts.

Verification Success Criteria: The verification shall be considered successful when demonstration shows that crew have the capability to suppress and inhibit alerts, and return alerts to their nominal (fully enabled) state.

V-HLS-S-HMTA-0509 Alert Filtering

Statement: Demonstration. The automated filtering of multiple and mixed priority alerts shall be verified by demonstration of flight representative simulation. The simulation shall include multiple, simultaneous low-priority alerts with high priority alerts that can occur during dynamic phases of flight such as docking with CSV and lunar landing.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows that the Integrated Lander automatically filters alerts by inhibiting low priority alerts during dynamic phases of flight and combining multiple low-level alerts to prevent alert flooding.

V-HLS-S-HMTA-0381 Audio Alert Sound Level

Statement: Test. The loudspeaker non-speech auditory annunciation levels shall be verified by test. The measurements shall be made within the vehicle in the flight configuration with integrated GFP, 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).

Verification Success Criteria: The verification shall be considered successful when the test indicates that, for each temporal component of the annunciation, the level is more than the above the ambient noise level at each expected work and sleep station location.

V-HLS-S-HMTA-0382 Reverberation Time

Statement: Analysis and Test. The reverberation time limit shall be verified by test and analysis. Field-testing shall be used to measure the reverberation time inside the actual flight vehicle. The methodology given in ISO 3382, "Measurement of the Reverberation Time of Rooms with Reference to Other Acoustical Parameters," shall be used. Intermediate testing and analysis should be performed and reviewed by NASA to ensure confidence that compliance with this requirement will be met and to preclude late impacts to cost, schedule, and hardware.

Verification Success Criteria: The verification shall be considered successful when test and analysis show the reverberation time is less than 0.6 second in the 500-Hz, 1-kHz, and 2-kHz octave bands.

V-HLS-S-HMTA-0383 Alert Frequency

Statement: Analysis and Test. The frequency content of auditory alerts shall be verified by test and analysis.

Verification Success Criteria: The verification shall be considered successful when test and analysis show the frequency of alerts are measured in the frequency range of 200 Hz to 4000 Hz.

V-HLS-S-HMTA-0386 Set-Point Alerts

Statement: Analysis and Demonstration. Set-point alerts will be verified by analysis and demonstration. The analysis shall show that the alert system is capable of alerting crew if set points are out of bounds. A demonstration shall be performed for a representative set of tasks using a representative interface.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that the system alerts the crew when the set-points of applicable parameters are out of bounds and the demonstration shows that setting applicable parameters out of bounds triggers associated alerts.

V-HLS-S-HMTA-0387 Audio Annunciation Silencing

Statement: Demonstration. The crew's ability to silence an audible alert that would otherwise annunciate continuously shall be verified by demonstration. The manual control to initiate a system-wide alert shall be verified by demonstration in flight-ready hardware and software of all the different types of triggered alerts and that the crew can silence each.

Verification Success Criteria: The verification shall be considered successful when demonstration shows the crew is able to manually silence all relevant alerts.

V-HLS-S-HMTA-0388 Visual and Auditory Annunciation Failures

Statement: Demonstration. The capability for crew to test for failure of visual and auditory annunciators shall be verified by demonstration using flight representative hardware and software. The demonstration shall include both functional and failed annunciators to verify system response.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows that the annunciator test correctly shows whether the system is working or a fault is identified with the annunciator system for all cases.

V-HLS-S-HMTA-0389 Visual Alerts - Red

Statement: Inspection. Visual Alerts - Red shall be verified by inspection of the visual indicator for all emergency and warning alerts.

Verification Success Criteria: The verification shall be considered successful when visual inspection indicates a single shade of red is used for all emergency and warning alerts.

V-HLS-S-HMTA-0390 Visual Alerts - Yellow

Statement: Inspection. Visual Alerts – Yellow shall be verified by inspection of the visual indicator for all caution level alerts.

Verification Success Criteria: The verification shall be considered successful when visual inspection indicates a single shade of yellow is used for all caution level alerts.

V-HLS-S-HMTA-0491 Color Usage

Statement: Inspection. Color usage shall be verified by inspection. An inspection shall be performed on the GUI displays, indicator lights, and labeling to confirm they meet the characteristics listed in HLS-RQMT-006, Table C-28: Integrated Lander Color Usage.

Verification Success Criteria: The verification shall be considered successful when the inspection of the GUI displays, indicator lights, and labels in the Integrated Lander meet the characteristics listed in HLS-RQMT-006, Table C-28: Integrated Lander Color Usage.

V-HLS-S-HMTA-0492 Flashing Indicator Standards

Statement: Demonstration. The use of flash coding for events requiring immediate crew attention or action shall be verified by demonstration of flight representative simulation of flashing indicators. The demonstration shall include lower and higher priority notifications and the ability for crew to terminate flashing notifications.

Verification Success Criteria: The verification shall be considered successful when demonstration shows that a) flashing indicators are used only for events that require immediate crew attention or action; b) low priority notifications flash at a frequency of 0.8 HZ with duty cycle of 70% on; c) high priority notifications flash at a frequency of 3 HZ with duty cycle of 50% on; d) flashing is synchronized across all cockpit display units; and e) crew are able to terminate flashing that persists for more than 10 seconds.

4.8.10 Crew Interface Labeling

V-HLS-S-HMTA-0391 Label Provision

Statement: Inspection and Test. The software and hardware labeling of crew interfaces shall be verified through inspection and test. A comprehensive inspection of task-analysis-derived labeling requirements vs. documented labels in labeling plan or

drawings shall be conducted. An inspection shall be conducted to ensure that labels, display formats, and OpNom are consistent. A comprehensive inspection shall be conducted to ensure that these required labels are designed and placed appropriately to support task performance. A HITL test on conjunction with HLS-S-HMTA-0273 shall be performed for select tasks, as agreed to through JTP, to evaluate usability of labeling in operational tasks.

Verification Success Criteria: The verification shall be considered successful when inspection and test show that crew interfaces are identified with the required labeling that are consistent with the OpNom and display format standards, and selected tasks have passing SUS score.

V-HLS-S-HMTA-0399 Labeling of Hazardous Substances

Statement: Inspection. The labeling of hazardous substances shall be verified by inspection. Inspection shall show that the labeling of hazardous substances is in accordance with HLS-RQMT-006 Table C-29: Hazardous Substance Labeling and hazard risk as documented in the HMST. Label and trash container drawings shall be inspected to verify that hazard labels are implemented.

Verification Success Criteria: The verification shall be considered successful when inspection shows that substance hazard type and hazard level have been characterized and hazardous substance containers are labeled in accordance with HLS-RQMT-006 Table C-29: Hazardous Substance Labeling.

4.9 Automated and Robotic Systems Design

V-HLS-S-HMTA-0400 Automated and Robotic System Provision

Statement: Demonstration and Analysis. Human/Automation task allocation must be designed with not only consideration for what is possible to automate, but what the implications of automated/robotic allocation are. Effective human-automation task allocation should test the effects on crew and ground user situation awareness. Crew task analysis shall determine when crew cannot reliably, safely or efficiently perform the tasks. Demonstration shall show that the automated system can perform the task when crew is cannot reliability, safely or effectively.

Verification Success Criteria: Verification shall be considered successful when the demonstration shows that automated systems are able to safely and effectively complete their analytically determined tasks with or without human interaction and supervision.

V-HLS-S-HMTA-0403 Automation Levels

Statement: Demonstration and Test. Crew interfaces to automated and robotic systems shall be verified by HITL demonstration and test. Demonstration and test shall include both nominal and off nominal operational conditions and the appropriate automation levels, as identified by the crew task analysis and trade analysis. The trade analysis on

human-system performance should consider workload, situational awareness and task performance time under the various nominal and off nominal conditions identified in crew task analysis. Interface demonstration must show the crew can operate the systems safely and reliably, while maintaining situational awareness for the given task. A HITL test must show that the crew interface enables appropriate workload and task performance time. The demonstration and test must be conducted with and without the presence of anomalies agreed to by the JTP and may be conducted concurrently.

Verification Success Criteria: The verification shall be considered successful when both the demonstration and test are successful. The demonstration shall be considered successful when it shows that crew is able to control automated and robotic systems through the provided interfaces with the appropriate SA, workload level (as identified in HLS-S-HMTA-0012 and -0013), and confirm that the expected human-system performance documented in the trade analysis are met or exceeded. In addition, the test shall be considered successful when it shows that the crew is able to control the automated and robotics systems with appropriate task performance time, as identified in the crew task analysis.

V-HLS-S-HMTA-0404 Automation Level Status Indication

Statement: Demonstration. Demonstration shall be performed with flight representative hardware and software to simulate a variety of automation status levels and transitions between levels.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows automation status information, including when the system changes between levels of automation and simulation of a variety of automation status levels, is provided to crew and remote operators.

V-HLS-S-HMTA-0406 Automated and Robotic System Arbitration

Statement: Analysis and Test. Automated and Robotic System Arbitration shall be verified by Analysis and Test. An analysis shall be performed to identify potential catastrophic and critical hazards that could result from failure to correctly accept input from and arbitrate between multiple automated and robotic operators. Controls that mitigate these hazards shall be verified by test. The test of select human system interaction tasks that involve commanding from multiple operators shall be performed using flight representative hardware and software to verify success of related hazard controls. Verification of HMTA-0406 should be performed in conjunction with HLS-S-SMA-0005 Mitigate Hazardous Software Behavior and HLS-S-SMA-0014 Control Critical Hazards.

Verification Success Criteria: The verification shall be considered successful when analysis and test shows that automated and robotic systems arbitrate between multiple operators and perform tasks safely and without degradation.

V-HLS-S-HMTA-0407 Automated and Robotic System Operation – with Communication Limitations

Statement: Analysis and Test. Automated and Robotic System Arbitration shall be verified by Analysis and Test. A task analysis and hazard analysis shall be performed to identify potential catastrophic and critical hazards that could result from failure to send and receive commands and perform tasks in the presence of communication latency and intermittent transmission related to remote operations, as documented in Interface Requirements Documents (e.g. HLS-IRD-004). Controls that mitigate these hazards shall be verified by a functional/performance test. A Human-in-the-Loop (HITL) test of select human-system interaction tasks that involve commanding shall be performed using flight representative hardware and software that involve remote operations in the presence of communication latency and intermittent transmission.

Verification Success Criteria: This verification shall be considered successful when the analysis and test shows automated or robotic systema are capable of receiving and sending commands and performing tasks in the presence of a fixed and variable communication latency and intermittent transmission related to remote operations; and when the HITL test shows task performance compliance with performance metrics specified in HLS-S-HMTA-0273, HLS-S-HMTA-0012, HLS-S-HMTA-0013. This analysis and test can be combined with verification activities for Remote Operations or Interface Requirements Document requirements.

V-HLS-S-HMTA-0408 Automation and Robotics Shut Down Capabilities

Statement: Demonstration. Demonstration using flight representative hardware and software shall show that the relevant automated and robotic systems can be shut down by crew and remote operator command, including any redundant paths in the control chain.

Verification Success Criteria: This verification shall be considered successful when the demonstration shows crew and remote operators have the ability to shut down predetermined automated and robotic systems.

V-HLS-S-HMTA-0409 Automation and Robotics Override Capabilities

Statement: Demonstration. Demonstration using flight representative hardware and software shall show that the relevant automated and robotic systems can be overridden by an alternate crew or remote operator command, including any redundant paths in the control chain.

Verification Success Criteria: The verification shall be considered successful when the demonstration shows that the crew and remote operators have the ability to override automated and robotic systems.

5 Subsystem Verifications

5.1 Integrated Lander IVA Suit Subsystem

V-HLS-S-IVA-0001 IVA Protection from Cabin Depressurization

Statement: Inspection and Test. IVA protection from cabin depressurization capability shall be verified by inspection and test. An inspection shall be performed to show IVA suits are planned to be worn during dynamic phases of flight and are available during non-dynamic phases of flight. A test shall also be performed by a human subject using flight-like IVA suit subsystem, flight-like ECLSS interfaces and consumables (including breathing gas and cooling) to verify suit hardware operability at flight representative differential suit pressure in a reduced pressure cabin environment.

Verification Success Criteria: The verification shall be considered successful when:

- the inspection shows that the IVA suit is planned to be worn during all dynamic phases of flight and will be readily available during non-dynamic phases of flight,
- and the test shows that the IVA suit subsystem can operate in a reduced pressure cabin environment of less than 0.50 psia.

V-HLS-S-IVA-0002 IVA Suit Hypoxia Prevention

Statement: Analysis and Test. IVA suit hypoxia prevention capability shall be verified by analysis and test. The analysis shall include a review of the IVA suit subsystem design and hardware to ensure a piO_2 1-hr time weighted average of ≥ 2.46 psia with an absolute minimum of 2.36 psia during nominal operations. The test shall validate the results of the analysis for all operational suit configurations, as dictated by contractor design and operations timeline.

Verification Success Criteria: The verification shall be considered successful when both test and analysis indicate that the IVA suit subsystem is able to maintain the inspired oxygen partial pressure greater than the absolute minimum and maintain the 1-hour time-weighted average greater than or equal to time-weighted average in all operational suit configurations, as dictated by contractor design and operations timeline

V-HLS-S-IVA-0003 IVA Suit DCS Prevention

Statement: Analysis and Test. IVA suit DCS prevention capability shall be verified by analysis and test. The analysis shall include a review of the IVA suit subsystem design to ensure minimum suit pressures and FiO2 meet HLS-RQMT-006, Table E-1: Minimum Pressure/ FiO2 of the IVA Suit Subsystem During a Depressurization Scenario. The test shall support the analysis.

Verification Success Criteria: The verification shall be considered successful when both test and analysis indicate that the IVA suit subsystem meets the minimum allowable suit pressure and FiO2 as denoted in HLS-RQMT-006, Table E-1: Minimum Pressure/ FiO2 of the IVA Suit Subsystem During a Depressurization Scenario.

V-HLS-S-IVA-0004 IVA Suit Barotrauma Prevention

Statement: Demonstration. IVA suit barotrauma prevention capability shall be verified by demonstration. The demonstration shall include pausing the IVA suit subsystem at increments, defined by task analysis, during pressurization and depressurization. It shall also include increasing and decreasing pressure after the pause to assess whether the pressure change can be continued and/or reversed.

Verification Success Criteria: The verification shall be considered successful when demonstration shows the IVA suit subsystem is able to pause any changes in suit pressure within 1 psi of the pause command and reverse pressure change for all defined pressure profiles as determined by the mission.

V-HLS-S-IVA-0005 IVA Suit Rate of Pressure Change

Statement: Analysis and Test. IVA suit rate of pressure change capability shall be verified by analysis and test. An analysis shall be performed to show that for pressure changes greater than 1.0 psi, the IVA suit subsystem will maintain a rate of change of ≤ 13.5 psi/min including inadvertent setting inputs and that the rate of pressure change in the IVA suit subsystem per design will not introduce injury to the crew. A test shall be performed using flight-like hardware to verify the IVA suit subsystem can withstand pressure changes up to the rate of pressure change in the IVA suit subsystem per design.

Verification Success Criteria: The verification shall be considered successful when:

- The analysis shows that the IVA suit subsystem will maintain a rate of pressure change of ≤ 13.5 psi/min for commanded pressure changes greater than 1.0 psi,
- The analysis shows that the rate of pressure change in the IVA suit subsystem per design does not introduce injury to the crew, *and,*
- The test shows the IVA suit subsystem can withstand pressure changes up to the rate of pressure change in the IVA suit subsystem per design.

V-HLS-S-IVA-0006 IVA Suit CO_2 Washout

Statement: Test and Analysis. IVA suit CO_2 washout capability shall be verified by test and analysis. The test shall be performed by a number of human subjects for a duration supported by defined mission assets in task analysis and with flight-like hardware, both jointly agreed upon by the JTP, and over metabolic loads defined by V-HLS-S-IVA-0007 to verify carbon dioxide partial pressure control. The test shall utilize the standardized testing methodology as published in NASA/TM-2020-220525, Bekdash, et al., April 2020. The analysis shall take the results of the CO_2 exposure testing and model those results across the range of expected crewmembers, metabolic loads, suited durations as defined by task analysis. Other relevant factors (such as IVA suit subsystem flow rate) should be included if they have a significant effect on CO_2 exposure.

Verification Success Criteria: The verification shall be considered successful when the test and analysis shows the IVA suit subsystem complies with the limits defined in HLS-

RQMT-006, Table E-2: IVA Suit Subsystem Inspired CO_2 Partial Pressure (P_iCO_2) Limits across the planned metabolic loads, IVA suit subsystem flow rates and for a duration supported by defined mission assets in task analysis.

V-HLS-S-IVA-0007 IVA Suit Thermal Loads

Statement: Analysis. Accommodation of IVA suit thermal loads capability shall be verified by analysis. The analysis shall be informed by expected metabolic loads as determined via task analysis and be performed using validated and NASA-approved models.

Verification Success Criteria: The verification shall be considered successful when the analysis shows the IVA suit subsystem can dissipate thermal loads of at least 1000 BTU/hr for active suited operations and provide thermal atmosphere equivalent to the cabin Thermal Comfort Zone for passive suited operations.

V-HLS-S-IVA-0008 Suit Donning Duration

Statement: Analysis and Demonstration. IVA suit donning duration capability shall be verified by analysis and demonstration. A task analysis shall be performed to identify all tasks required by the crew to de-stow IVA suit subsystem hardware, don IVA suits, and perform leak checks, along with the time and accuracy requirements for each of the tasks in that scenario. A timeline analysis shall be performed to identify the minimum operational timeline available to perform the tasks identified in the task analysis. A demonstration shall be performed by a full crew of human subjects using flight-like hardware in a flight representative cabin and configuration to measure the task completion times and error rates for select tasks, as identified by the task analysis and agreed to by the JTP. The demonstration shall include flight-representative leak checks.

Verification Success Criteria: The verification shall be considered successful when all human subjects demonstrate the ability to perform select tasks, as identified by the task analysis and agreed to by the JTP, in less than or equal to the minimum operational timeline per the timeline analysis.

V-HLS-S-IVA-0009 Unassisted IVA Suit Donning

Statement: Demonstration. Unassisted IVA suit donning capability shall be verified by demonstration. The demonstration shall be performed by a number of human subjects, jointly agreed upon by the JTP, unassisted, with flight-like hardware. It shall include all steps from pre-donning (including destowing IVA suit subsystem hardware) and post-donning activities (including a leak check and addition of relevant consumables).

Verification Success Criteria: The verification shall be considered successful when the demonstration shows unassisted IVA suit subsystem donning, from start to full pressure protection.

V-HLS-S-IVA-0010 Breathing Apparatus to Suit Transition

Statement: Analysis and Demonstration. Breathing apparatus to the IVA suit transition capability shall be verified by analysis and demonstration. A task analysis shall be performed to identify all tasks required to be completed by the crew to transition from a breathing mask to an IVA suit subsystem configuration. This task analysis shall identify operations required to purge the IVA suit subsystem of a toxic atmosphere in which the crewmember has a clean, breathable atmosphere protecting the crewmember's oronasal and ocular regions and include those applicable tasks which must be performed during the transition. A demonstration shall be performed by human subjects using flight-like hardware in a flight-like cabin.

Verification Success Criteria: The verification shall be considered successful when the human subjects demonstrate the tasks required to transition from a breathing apparatus to an IVA suit subsystem configuration, which is shown to provide a safe, breathable atmosphere protecting the crewmember's oronasal and ocular regions per the task analysis, in ≤ 30 seconds.

V-HLS-S-IVA-0011 IVA Suit Task Performance

Statement: Analysis and Demonstration. IVA suit task performance capability shall be verified by analysis and demonstration. A task analysis shall identify suited tasks that should be tested for each mission scenario, along with the time and accuracy requirements for each of the tasks in that scenario. The demonstration shall be performed by suited human subjects with flight-like hardware in a pressurized and unpressurized configuration to measure the task completion times and error rates for select tasks as identified by the task analysis and agreed to by the JTP tested independent of gravity.

Verification Success Criteria: The verification shall be considered successful when the analysis and demonstration shows the ability to perform select tasks as identified by the task analysis and agreed to by the JTP in both pressurized and unpressurized configurations independent of gravity.

V-HLS-S-IVA-0012 IVA Suit Communication Capability

Statement: Demonstration and Inspection. IVA suit communication capability shall be verified by demonstration and inspection. The demonstration shall include flight-like hardware and simulate scenarios requiring communication among crewmembers and between crewmembers, spacecraft systems and NASA MCC. The inspection shall include an evaluation of engineering drawings of all relevant hardware.

Verification Success Criteria: The verification shall be considered successful when the demonstration and inspection shows proof of the communication pathways when crew are suited and within the vehicle at any time.

V-HLS-S-IVA-0013 IVA Suit Helmet

Statement: Analysis, Test, and Demonstration. IVA suit helmet properties shall be verified by analysis, test, and demonstration. The analysis shall include an evaluation of the helmet geometry, IVA suit flexibility, and crew mobility to verify the FOV. The test shall measure the helmet's optical properties using a flight-like visor with any internal light sources in a flight-like configuration. The demonstration shall be performed by human subjects with flight-like hardware in flight-like configurations to validate the results of the analysis and test using task completion times and error rates, for select tasks as identified by task analysis and agreed to by the JTP, as a measure.

Verification Success Criteria: The verification shall be considered successful when:

- the analysis shows the IVA suit helmet provides a FOV and optical qualities sufficient to perform all suited tasks, *and,*
- the demonstration shows the helmet allows for crew to perform select tasks as identified by task analysis and agreed to by the JTP, as a measure.

V-HLS-S-IVA-0014 IVA Suit Status Display

Statement: Analysis and Demonstration. IVA suit status display capability shall be verified by analysis and demonstration. The analysis shall include an evaluation of relevant hardware drawings and models. The demonstration shall include an assessment of display usability by a sample of representative user-like individuals with flight-like hardware in accurate postures under all potential flight-like conditions.

Verification Success Criteria: The verification shall be considered successful when:

- the analysis shows hardware is available to display relevant suit pressure and consumables status information, *and,*
- the analysis shows hardware is available to telemeter relevant suit pressure and consumables status information to NASA MCC, and,
- the demonstration shows that representative user-like individuals have unobstructed view of the IVA suit subsystem status display hardware in the relevant user configurations and are capable of utilizing the display hardware with acceptable levels of accuracy as defined by task analysis and by the Program.

V-HLS-S-IVA-0015 IVA Suit Status Information

Statement: Inspection, Demonstration, and Test. Provision of IVA suit status information capability shall be verified by inspection, demonstration, and test. The inspection shall include an evaluation of engineering drawings of all relevant hardware. The demonstration shall include display of all potential suit pressure and consumable values, as well as any related caution/warnings to the precision that is operationally relevant. The demonstration should include display of ppO_2, $ppCO_2$, as well as any related caution/warnings to the precision that is operationally relevant. The test shall include measurements of actual parameters compared with the status displayed by the IVA suit subsystem.

Verification Success Criteria: The verification shall be considered successful when:

- the inspection and demonstration shows relevant IVA suit subsystem information to the precision required and related warnings, *and,*
- the test confirms accuracy of the information.

V-HLS-S-IVA-0016 IVA Suit Settings Adjustment

Statement: Demonstration and Test. IVA suit settings adjustability, identified as relevant by the task analysis, shall be verified by demonstration and test. The demonstration shall include manipulation by human subjects in a flight-like mockup in both pressurized and unpressurized configurations as defined by task analysis. The test shall include measurements of actual parameters compared with set-points chosen by the test subject.

Verification Success Criteria: The verification shall be considered successful when:

- the demonstration shows that each relevant IVA suit subsystem parameter, identified by task analysis, can be controlled by the crew, *and,*
- the test confirms accuracy of the setpoint command.

V-HLS-S-IVA-0017 IVA Suit Telemetry and Biomed

Statement: Analysis and Demonstration. IVA suit telemetry and biomed capability shall be verified by analysis and demonstration. The analysis shall include and evaluation of relevant hardware drawings and models. The demonstration shall include biomed collection and be performed by a human subject using flight-like hardware in flight-like configurations.

Verification Success Criteria: The verification shall be considered successful when:

- the analysis shows hardware is available to telemeter biomed to MCC on demand, and,
- the demonstration shows telemetry and biomed can be collected from the human subject.

V-HLS-S-IVA-0019 IVA Suit Particulate Control

Statement: Analysis and Demonstration. IVA suit particulate control capability shall be verified by analysis and demonstration. An analysis shall be performed to show the IVA pressure suit hardware is designed to preclude blockage, damage, and degradation from particulate exposure. An analysis shall be performed to show the IVA pressure suit is designed to prevent particulate from creating a catastrophic hazard in the IVA pressure suit. A demonstration shall be performed by a human subject using flight-like hardware to show the IVA pressure suit is designed and crew can perform relevant tasks to prevent particulate from creating a catastrophic hazard in the IVA pressure suit.

Verification Success Criteria: The verification shall be considered successful when:

1. The analysis shows that the IVA pressure suit design precludes blockage, damage, and degradation of suit loop hardware from particulate exposure *and*,

2. The analysis and demonstration shows that the IVA pressure suit prevents particulates from creating a catastrophic hazard due to their presence in the crewmember's oronasal and ocular regions.

V-HLS-S-IVA-0020 IVA Suit Contaminant Exposure

Statement: Test. IVA suit contaminant exposure capability shall be verified by test.

Verification Success Criteria: The verification shall be considered successful when the test shows the IVA suit subsystem maintains the contaminants that can be generated within the IVA pressure suit below the SMAC limits as defined in JSC-20584 and/or JSC Toxicology defined limits for the worst-case suited duration.

V-HLS-S-IVA-0021 IVA Suit Waste Management

Statement: Analysis, Inspection, Demonstration, and Test. IVA suit waste management capability shall be verified by analysis, inspection, demonstration, and test. A task analysis shall be performed to determine body waste management operations, functions and accommodations in applicable mission phases and environments. The analysis shall be performed to confirm that expected body waste containment designs are appropriate for the waste types and environments. Engineering drawings and models shall be inspected to verify these components have been incorporated in accordance with all body waste management activities and supplies identified in the task analysis. The demonstration shall be performed with flight-like hardware to show containment independent of gravity and shall consist of a release into the collection system. The test shall be performed to confirm compatibility of the containment design with worst-case waste matter (maximum volume and maximum flow rate as defined in HLS-RQMT-006, Table E-3: IVA Suit Subsystem Body Waste Associated with Contingency Caloric Intake) and environment for the mission duration.

Verification Success Criteria: The verification shall be considered successful when:

- the analysis shows that the body waste containment design is appropriate for the waste types and environments,
- the demonstration shows that an operator can use the body waste management system and that all particles are contained,
- the inspection shows that a body waste management system has been provided and includes stowage, accommodation, functionality, and disposal of body waste management events and supplies for the quantities and rates, *and,*
- the test confirms compatibility of the design with worst-case waste matter and environment for the mission duration.

V-HLS-S-IVA-0022 IVA Suit Nutrition and Potable Water

Statement: Demonstration. Delivery of IVA suit nutrition and potable water capability shall be verified by demonstration. The demonstration shall include human subjects in a pressurized and unpressurized flight-like configuration of the IVA suit subsystem and/or safe haven with actual or simulated mock-ups of consumables. Demonstration

shall include subjects having access to and using consumables in a manner that can satisfy the duration required by the ConOps and task analysis.

Verification Success Criteria: The verification shall be considered successful when demonstration shows the capability to access and consume 2L of water per crewmember per day and 1000 kcal of nutrition per crewmember per day by the IVA suit subsystem and/or safe haven.

V-HLS-S-IVA-0023 IVA Suit Medical Administration

Statement: Demonstration. IVA suit medical administration capability shall be verified by demonstration. The demonstration shall include human subjects using flight-like hardware in flight-like configurations.

Verification Success Criteria: The verification shall be considered successful when demonstration shows the capability of the IVA suit subsystem to administer medication to a suited, pressurized crewmember.

5.2 Integrated Lander Food Subsystem

V-HLS-S-HMTA-0452 Food Quality

Statement: Test and Analysis. Food quality shall be verified by test and analysis. A test shall be performed by a laboratory approved by the NASA JSC Space Food Systems Laboratory and the NASA Nutritional Biochemistry Laboratory after a representative food complement has been stored for the expected duration of the mission in a flight representative storage environment in order to verify nutrition. Analysis shall be performed to verify safety and nutrition during all phases of the mission, including launch, pressure changes, temperature changes, and storage (conditions and duration).

For freeze-dried and beverage packaging, in-line leak testing shall be conducted once for at least every 20 packages. For freeze-dried, shelf stable, and beverage packaging 100% of the packaged products shall be visually inspected and tested under vacuum for package seal integrity and safety. Water activity/moisture testing shall also be completed for all freeze-dried foods and beverage powders, as well as snack products that may fall within a range that could grow microorganisms (e.g. cookies, food bars, and dried fruits) (at least 3 samples per lot). As guidance, for leak testing, which is destructive, NASA verifies that one in every 20 packages can hold 10 psi pressure with less than 0.5 psi pressure decay in 1 minute (5 psi for beverage packaging). For vacuum seal integrity, which is not destructive, NASA tests 100% of the packaging. For example, food packaged at 21 mmHg vacuum is tested at 17 mmHg vacuum for 1 minute and held at ambient for at least 16 hours to verify if any package loses vacuum. 100% of packages are visually inspected. The vacuum level varies depending on the food product. In cases where water activity is higher than 0.60, additional methods of stability shall be specified by the provider (e.g., preservatives, etc.).

For retort thermostabilized foods products, 100% of the production lot shall be visually inspected in accordance with MIL-PRF-44073 Section 3.1.4.1 and tested under pressure for package seal integrity and safety.

Verification Success Criteria: The verification shall be considered successful when test and analysis show the food system meets safety and nutrition requirements during all phases of the mission.

V-HLS-S-HMTA-0453 Food Acceptability

Statement: Test and Analysis. Food acceptability shall be verified by test and analysis. A test shall be performed using the flight-like food complement. Testing shall include at least three analog simulations, each with at least 4 subjects simulating mission tasks and exclusively consuming the food system over the expected mission length. Test subjects will consume prepared food and rate it on a 9-pt hedonic scale. This scale is commonly used and accepted by both food industry and academia. All state and regulatory requirements shall be met for sensory test panels. The test shall be coordinated with HLS Joint Test Panel. An analysis shall be conducted to show that all food items meet a minimum acceptability standard from packaging through consumption.

Analog means a controlled isolated and confined environment, with crew representative subjects and a similar tempo as that expected for the mission, to confirm that the food system will be consumed and support health and performance through mission relevant tasks. This environment also prevents subjects from obtaining other food during the test period. Research has documented that one of the biggest issues in dietary evaluations is compliance.

Verification Success Criteria: The verification shall be considered successful when the test shows that subjects consume at least 90% of calories and other nutrients throughout test and rate 90% of available items ≥ 6 on a 9-pt hedonic scale, and when analysis shows that food items provided by the system maintain that acceptability from packaging through consumption. Alternatively, the verification shall be considered successful when the food as prepared and used is considered acceptable ($\geq$ 6 on a 9-pt hedonic scale) by >25 sensory panelists. All human testing shall follow relevant Institutional Review Board criteria.

V-HLS-S-HMTA-0504 Food Variety

Statement: Inspection or Test. The food variety within the menu shall be verified through inspection by a NASA dietitian. Alternatively, testing shall be performed using three analog simulations, each with 4 subjects performing relevant tasks and consuming this system over expected mission length (variety specified here supports 7 to days) to verify that the variety in the system is acceptable and supports adequate intake over the mission duration (subjects consume at least 90% of calories and other nutrients throughout test). Analog means a controlled isolated and confined environment, with astronaut-like subjects and a similar tempo as that expected for the mission, to confirm

that the food system will be consumed and support health and performance through mission relevant tasks. This environment also prevents subjects from obtaining other food during the test period. Research has documented that one of the biggest issues in dietary evaluations is compliance.

Verification Success Criteria: The verification shall be considered successful when a NASA dietitian reviews the menu and determines it provides an acceptable nutritional variety for crew over the length of the mission without excessive repetition.

V-HLS-S-HMTA-0454 Food Caloric Content

Statement: Test and Analysis. Food caloric content shall be verified by test and analysis. A test shall be performed by a laboratory approved by the NASA JSC Space Food Systems Laboratory and the NASA Nutritional Biochemistry Laboratory to determine caloric content. An analysis shall be performed to show that the mission menu meets the caloric requirements.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that the mission menu meets minimum energy requirements per day, and the test shows that the food items will meet the caloric requirements used in the mission menu analysis.

V-HLS-S-HMTA-0456 Food Macronutrients

Statement: Test and Analysis. Food macronutrients shall be verified by test and analysis. A test shall be performed by a laboratory approved by the NASA JSC Space Food Systems Laboratory and the NASA JSC Nutritional Biochemistry Laboratory to determine macronutrient content. An analysis shall be performed on the test data to determine the nutritional value of the mission menu.

Verification Success Criteria: The verification shall be considered successful when test shows that the food items will have expected nutritional value and analysis shows that the resulting menu meets the daily dietary intake requirements of the crew during the operational timeline, as specified in Table E-5: Macronutrient Guidelines for Spaceflight.

V-HLS-S-HMTA-0457 Food Micronutrients

Statement: Test and Analysis. Food micronutrients shall be verified by test and analysis. A test shall be performed by a laboratory approved by the NASA JSC Space Food Systems Laboratory and the NASA JSC Nutritional Biochemistry Laboratory to determine micronutrient content. An analysis shall be performed on that test data to determine the nutritional value of the mission menu.

Verification Success Criteria: The verification shall be considered successful when test shows that the food items will have expected nutritional value and analysis shows that the resulting menu meets the daily dietary intake requirements of the crew during the operational timeline, as specified in Table E-6: Micronutrient Guidelines for Spaceflight.

V-HLS-S-HMTA-0458 Microorganism Level Controls for Food Safety

Statement: Test and Inspection. Microorganisms levels shall be verified by test and inspection. A test shall be performed to determine microorganism levels in production and in individual food items to make sure that they do not exceed those specified in HLS-RQMT-006, Table E-7: Food Microorganism Levels. If Commercially Sterile Products are procured for the mission and maintained in their original packaging, an inspection of package integrity shall be performed instead of a microbiological test.

Verification Success Criteria: The verification shall be considered successful when test and inspection show that the microorganisms sampled from flight packaged food items do not exceed the Food Microorganism Levels specified in HLS-RQMT-006,Table C.21: Food Microorganism Levels. If Commercially Sterile Products are procured for the mission and maintained in their original packaging, verification shall be considered successful when inspection shows that the packaging is intact and un-damaged and prevents contamination.

V-HLS-S-HMTA-0103 Food Suitability for Microgravity and Partial-Gravity

Statement: Inspection and Demonstration. An inspection of Food Plan shall be performed to identify suitability of food products based on NASA experience with food consumption in the micro-gravity environment. Demonstration shall be performed on a sample of select food products to evaluate suitability in a flight-like simulation of handling, preparation, consumption, and cleanup.

Verification Success Criteria: The verification shall be considered successful when the inspection and demonstration show that the food system provides food products that control the release of crumbs and liquids during preparation, consumption, and cleanup.

V-HLS-S-HMTA-0100 Meal Schedule Accommodation

Statement: Test. HITL test shall be performed with flight-representative food system in flight configuration to measure time for a full crew to unstow, prepare, consume, and clean up for breakfast, lunch, and dinner meals. The demonstration shall be coordinated with HLS JTP.

Verification Success Criteria: The verification shall be considered successful when the test shows that the food products for each full crew meal of breakfast, lunch, and dinner can be un-stowed, prepared, consumed, and cleaned up in no more than 60 minutes.

V-HLS-S-HMTA-0505 Food Packaging Safety

Statement: Test. A white glove test shall be performed on the exterior surfaces of a sample of food packages to check for presence of edges, burrs, or small pieces that may cause injury or damage. The test shall also be performed on surfaces and edges and for presence of small pieces after opening packages for preparation and consumption.

Verification Success Criteria: The verification shall be considered successful when the test shows that the food system packaging does not have or generate sharp edges or small pieces that can cause damage or injure the crew.

V-HLS-S-HMTA-0506 Food Package Labeling

Statement: Inspection. Visual inspection drawings or of a sample of flight-representative food packages shall be performed to confirm completeness of the labeling.

Verification Success Criteria: The verification shall be considered successful when inspection confirms that final food packages are labeled with a name that accurately describes the food product, the production date, the best use by date, and known food allergens.

5.3 Integrated Lander Medical Kit Subsystem

V-HLS-S-HMTA-0119 Durable Medical Hardware and Supplies

Statement: Inspection and Demonstration. An inspection of the Medical Kit contents shall be performed against the NASA list of required durable medical hardware and supplies. A HITL demonstration shall be performed with flight representative, integrated Medical Kit subsystem to evaluate the operational usability for response to planned Integrated Lander medical scenarios, including data quality for crew and flight surgeon medical diagnosis.

Verification Success Criteria: The verification shall be considered successful when inspection and demonstration show that the Medical Kit provides the required durable medical hardware and supplies in an integrated system with NASA-provided pharmaceuticals and is usable by crew and ground-based physicians for planned Integrated Lander medical scenarios.

5.4 Integrated Lander Waste Management Subsystem

V-HLS-S-HMTA-0111 Body Waste Management Capability

Statement: Inspection and Test. Provision to accommodate collection, containment, and disposal of body waste for both males and females shall be verified by inspection and test. Engineering drawings and models shall be inspected to verify that a body waste management system has been incorporated into the Integrated Lander design in accordance with expected body waste management activities and associated supplies. A HITL test shall utilize flight representative mockup/hardware in flight configuration(s) with representative male and female subjects performing selected tasks, as agreed to through JTP, to evaluate usability of the active toilet system for micro- and lunar gravity environments.

Verification Success Criteria: The verification shall be considered successful when inspection and HITL testing show that the Integrated Lander includes an active toilet

system that is capable of collection, containment, and disposal of body waste for both males and females, functional in micro and lunar gravity.

V-HLS-S-HMTA-0479 Body Waste Quantities

Statement: Analysis, Demonstration, Inspection and Test. The collection and containment of fecal matter shall be verified by demonstration and inspection. The demonstration shall be performed with flight-like hardware to show containment independent of gravity. The demonstration shall consist of a release into the collection system, followed by a repeated release into the collection system. The inspection shall determine the volume of the collection system.

The collection and containment diarrhea discharge and vomitus shall be verified by demonstration and inspection. 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 inspection shall determine the volume of the collection system.

The collection and isolation of urine shall be verified by analysis or test and inspection. The analysis or test shall determine that the collection system can accommodate the specified flow rate. The inspection shall determine the volume of the collection system.

The collection and isolation of menses shall be verified by inspection. An inspection shall be performed to show that the waste management system design collects and contains menses.

Verification Success Criteria: The verification shall be considered successful when the inspection and demonstration show that the collection system can hold 500 g (1.1 lb) mass and/or 500 ml (16.9 oz) volume of fecal matter per crewmember, release can be collected, and release is contained. The verification shall be considered successful when the analysis shows that 150 g and 150 mL of fecal matter per crewmember per defecation at an average of two defecations per day are contained.

The verification shall be considered successful when the demonstration and inspection show that the collection system can collect and contain four diarrheal events per crewmember, per mission (volume of 500 ml (16.9 oz) diarrheal discharge per defecation) AND four vomitus events per crewmember, per mission (volume of 500 ml (16.9 oz) vomit per emesis) and that each release can be collected with no spillage or leakage, and each release is contained.

The verification shall be considered successful when the analysis or test shows that the collection system can collect and isolate from the crew environment urine that is discharged at the flow rate specified and when the inspection shows that the collection system can collect and isolate from the crew environment the amount of urine specified by the equation per crewmember for the duration of the mission, with a maximum volume of 1000mL per void with up to 6 events per crewmember per day.

The verification shall be considered successful when the inspection shows that the collection system can collect and isolate from the crew environment the amount of menses specified per female crewmember for the duration of the mission.

V-HLS-S-HMTA-0445 Capacity for Simultaneous Collection of Feces, Urine and Menses

Statement: Inspection and Test. The capacity for simultaneous collection and isolation of feces, urine and menses shall be verified by inspection and test. The inspection and test, using human simulant, shall determine the collection system is capable of accepting feces, urine and menses at the same time.

Verification Success Criteria: The verification shall be considered successful when the inspection and test using human simulant shows that the collection system can simultaneously collect and isolate from the crew environment the volume of feces, urine and menses.

V-HLS-S-HMTA-0449 Urine Stabilization

Statement: Analysis and Demonstration. Urine stabilization shall be verified by analysis and demonstration. The analysis shall include the type of urine stabilization and the rationale for using it. The demonstration shall be performed with flight like hardware for no less than the mission duration. The demonstration shall include the successful functional operations of adding the stabilization to the flight like system and storing of the urine plus stabilization for at least the mission length. Mission phases include docked phases with intermediate vehicles or crew return vehicles.

Verification Success Criteria: The verification shall be considered successful when the analysis shows that the method and amount of stabilization will accommodate all mission phases and when the demonstration shows that by adding the stabilization to the flight like system and storing of the urine and stabilizer for at least the mission length, the urine has not produced ammonia or precipitates for all mission phases.

V-HLS-S-HMTA-0450 WMS Unavailability Collection Options

Statement: Analysis and Demonstration. WMS Unavailability Collection Options shall be verified by analysis and demonstration. The analysis shall be conducted to determine if potential failures exist that could result in the Waste Management System becoming unavailable. The demonstration shall show that contingency collection method(s) are available, operable, and usable in the event of a failure that results in the Waste Management System becoming unavailable. Usability testing must be part of the development process to ensure successful crew interface design. A HITL demonstration shall utilize flight representative mockup/hardware in flight configuration(s) with representative male and female subjects, performing selected tasks, as agreed to through JTP, to evaluate usability of the contingency collection method(s).

Verification Success Criteria: The verification shall be successful when analysis identifies potential failures that could result in the WMS becoming unavailable, and demonstration shows that an operable and usable contingency collection method exists if those potential failures occur.

V-HLS-S-HMTA-0451 Crew Interface for Defecation

Statement: Inspection and Demonstration. The body waste management system provision of a seated crew interface opening shall be verified by inspection and demonstration. Engineering drawings and models shall be inspected to verify that the seated crew interface opening enables proper anus and urethra positioning in relation to the collection device for both male and female anatomy. Usability testing must be part of the development process to ensure successful crew interface design. A HITL demonstration shall utilize flight representative mockup/hardware in flight configuration(s) with representative male and female subjects, performing selective tasks, as agreed to through JTP, to evaluate usability of the seated crew interface opening.

Verification Success Criteria: Verification shall be successful when inspection and HITL demonstration show that a usable body waste management system seated crew interface opening accommodates both male and female anatomy.

V-HLS-S-HMTA-0443 Simultaneous Accommodation of Anatomical Interfaces

Statement: Analysis and Demonstration. 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.

Verification Success Criteria: 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.

V-HLS-S-HMTA-0444 Body Waste Containment

Statement: Analysis, Demonstration, Inspection, and Test. Body waste containment shall be verified by analysis, demonstration, inspection and test. A crew task analysis shall be performed to determine body waste management operations, functions and accommodations in applicable mission phases and environments. An analysis shall be performed to confirm that expected body waste containment designs are appropriate for the waste types and environments. Engineering drawings and models shall be inspected to verify these components have been incorporated in accordance with all body waste management activities and supplies identified in the crew task analysis. Demonstrations shall be performed using flight representative hardware in the flight configuration while exercising body waste management activities. A test shall be

performed to confirm compatibility of the containment design with worst-case waste matter and environment for the mission duration.

Verification Success Criteria: The verification shall be considered successful when analysis shows that the body waste containment design is appropriate for the waste types and environments and the demonstration shows that an operator can use the body waste management system and that all particles are contained, inspection show that a body waste management system has been provided and includes stowage, accommodation, functionality, and disposal of body waste management events and supplies for the quantities and rates, and test confirms compatibility of the design with worst-case waste matter and environment for the mission duration.

Appendix A Acronyms and Abbreviations

Acronyms	Abbreviations
3D	Three-dimensional
AC	Alternating Current
ACGIH	American Conference of Governmental Industrial Hygienist
ALARA	As Low As Reasonably Achievable
ANSI	American National Standards Institute
ARS	Atmosphere Revitalization System
BEI	Biological Exposure Indices
CAD	Crew Active Dosimeter
CMO	Chief Medical Officer
CO2	Carbon Dioxide
ConOps	Concept of Operations
DC	Direct Current
DCS	Decompression Sickness
DRD	Data Requirements Document
DRM	Design Reference Mission
E3	Electromechanical Environmental Effects
ECLSS	Environmental Control and Life Support System
EEE	Electrical, Electronic, and Electromechanical
EM	Electromagnetic
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
Env.	Environment
EVA	Extravehicular Activity
FFT	Fast Fourier Transform
FIO2	Fractional Inspiratory Volume for Oxygen
FMEA	Failure Modes and Effects Analysis
FPS	Fire Protection System
GFE	Government Furnished Equipment
GFP	Government Furnished Property
GN&C	Guidance, Navigation and Control
GUI	Graphical User Interface
HEA	Human Error Analysis
HEOMD	Human Exploration and Operations Mission Directorate
HIDH	Human Integration Design Handbook
HITL	Human-in-the-loop
HLS	Human Landing Systems
HMTA	Health and Medical Technical Authority
HQR	Handling Qualities Rating
IASIS	International Avionics System Interoperability Standards
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
IR	Infrared
IRD	Interface Requirements Document

Acronyms	Abbreviations
IVA	Intravehicular Activity
JSC	Johnson Space Center
JTP	Joint Test Panel
LOC	Loss of Crew
LOM	Loss of Mission
MPE	Maximum Permissible Exposure
NIR	Near-Infrared Radiation (update)
NMSUS	NASA Modified System Usability Scale
NRHO	Near Rectilinear Halo Orbit
O2	Oxygen
OpNom	Operations Nomenclature
PFE	Portable Fire Extinguisher
PIO2	Inspired Oxygen
ppCO2	Carbon Dioxide Partial Pressure
PPE	Personal Protective Equipment
ppO2	Oxygen Partial Pressure
PSIA	Pounds Per Square Inch Absolute
Qty	Quantity
Rad.	Radiation
Rev	Revision
RF	Radio-Frequency
RH	Relative Humidity
SA	Situational Awareness
SF	Space Flight
SI	International System of Units
SMA	Safety and Mission Assurance
SMAC	Spacecraft Maximum Allowable Concentrations
SME	Subject Matter Expert
SPE	Solar Particle Event
SPL	Sound Pressure Level
SUS	System Usability Scale (Update)
SWEG	Spacecraft Water Exposure Guidelines
TA	Technical Authority
TCS	Thermal Control System
TLV	Threshold Limit Value
TLX	Task Load Index
TPM	Permissible Material Temperature
TWA	Time Weighted Average
UV	Ultraviolet
VCN	Verification Closure Notice
VOC	Volatile Organic Compounds
Vol	Volume
WMS	Waste Management System

Appendix B Glossary

Glossary Term	Acronym	Definition
Critical Function		Mission capabilities or system functions that, if lost, would result in a critical personnel injury/illness, loss of mission, catastrophic event, or an abort. (Critical here refers back to SMA definition of critical hazard for personnel.)
Field-of-Regard		The solid angle that can be seen by an observer with eye and head movements.
Flight Configuration		The arrangement, orientation and operational state of system elements and cargo, vehicle cabin layout, flight software mode, and crew complement, clothing, and equipment in the applicable mission phase necessary in verification to evaluate the attributes called out in the requirement.
Flight Representative		Description of a test-article, to include hardware and software, used in verifications for which the attributes under evaluation are equivalent to the flight article. Example: Human-in-the-loop tests for spacecraft egress must use an equivalent cabin layout, seats and restraints, and hatch configuration and masses. For evaluations using software for displays and controls, the software must be flight like as must the associated controls. However, the propulsion system does not need to be flight representative in terms of functionality or performance functional, as it is not under evaluation.
Habitable Atmosphere		In a space system, the habitable atmosphere is a contained gaseous environment of controlled composition maintained within established pressure and temperature bounds to support human life. The ECLSS system provides, maintains, and revitalizes the habitable atmosphere.
Habitable Volume		In a space system, the habitable volume is an enclosed compartment that is sized and laid out to accommodate human crewmembers living and working activities. The habitable volume is normally provided with habitable

Glossary Term	Acronym	Definition
		atmosphere to support human crewmembers in shirt-sleeve attire.
Human-in-the-Loop Demonstration or Test	HITL Demonstration or Test	HITL demonstrations or tests utilize human subjects performing planned crew tasks using flight representative system hardware and/or software to evaluate the design during engineering development and requirement verification. HITL test/demo subject demographic needs may vary on the specific requirement being evaluated or verified.
Manual Control		Input by the onboard crew with the intent to directly affect spacecraft systems or operations, such as flight path, attitude, temperature, pressure, etc., within the capabilities of the control system. For a control loop where automated control is possible, manual control bypasses includes the ability to bypass the automation for one or more particular control loop(s), while also allowing options for blended manual and automated control.
Joint Test Panel	JTP	The purpose of the JTP is to coordinate crew interface design, operations, and human-in-the-loop (HITL) activities between the contractor and NASA. The JTP will designate HITL events where NASA crewmembers or NASA crewmember representatives are required. For HITL verification events, the JTP will provide guidance to the Provider on selection of crew tasks and scenarios for testing and facilitate scheduling of and crew health support for crew subjects. The goal of the JTP is to help the contractor achieve success at milestones and ultimately a certified design that supports successful crew operations.
Operator		Any human that monitors, commands, or interfaces with the space system during the mission, including Integrated Lander crew, lunar orbiting crew, lunar surface crew, and the Flight Control Team.
Safe Haven		A "safe haven" is defined as a separate A "safe haven" is defined as a separate pressurized volume in which the crew can

Glossary Term	Acronym	Definition
		survive until Integrated Lander facilitates crew ingress into the CSV. This can be met through a combination of EVA Spacesuit, IVA spacesuit, airlock, etc. The safe haven must provide required consumables and critical life support to the crew for a period of time sufficient to cover this return at any point in the mission. The atmospheric conditions that must be maintained include PIO2, ppCO2, pressure, air temperature, etc. Appropriate PPE may be used to temporarily provide these atmospheric conditions while the crew is establishing the safe haven. The crew must be able to issue commands from the safe haven, and Integrated Lander systems must be designed to provide the required capabilities (e.g. navigation, communication, propulsion, etc.) despite a depressurized cabin, a suited or relocated crew, etc.
Spacesuit		A spacesuit is a garment worn to keep a human alive in the harsh environment of outer space, vacuum and temperature extremes. There are two types of space suits: 1. IVA (intravehicular activity) spacesuits are meant to be worn inside a pressurized spacecraft as a safety precaution to provide life support, environmental protection, communication, and mobility for crew to perform necessary response and recovery operations in case of loss of cabin pressure or contaminated atmosphere. 2. EVA (extravehicular activity) spacesuits provide life support, environmental protection, data and communications, human mobility and agility, and interfaces for allowing crew members to perform spacewalk operations outside of the protective environment of a host vehicle (e.g., spacecraft, habitat, or rover) during

Glossary Term	Acronym	Definition
		both micro-gravity and partial-gravity surface missions.
Subjects		In context of HITL demonstrations or tests, subjects perform planned activities to evaluate the design. When specified, “crew subjects” are intended to be NASA crewmembers or crew representatives as selected by the JTP. Subjects (non-crew) may be selected by the Provider or JTP to represent crew users depending on the level of skill or experience needed for the evaluation. All HITL subjects must have appropriate test and operational procedures training to ensure valid evaluation.
Task Analysis		A Task Analysis is a methodical and iterative process that analyzes tasks allocated to the human by decomposing individual tasks into simpler actions (task steps) and identifying the task parameters and conditions that can either enable or constrain human interface interactions. The focus of the task analysis is on the human and how they interact with the hardware, software, procedures, and other users of the system to perform the tasks. The analysis is performed by mission phase and produces a detailed definition of the tasks which includes relevant task parameters such as which user is performing the task, triggers for steps within the task, planned task duration, task performance frequency, temporal demands and constraints, human interfaces, etc., as well as criticality, complexity, cognitive, and physical demands. These aspects of task analysis are used in human error potential analysis where, for critical and complex tasks, each step must be evaluated to inform design choices for minimizing design-induced error. These analyses are used to drive design, developmental HITL evaluation, and verification efforts for effectiveness, efficiency, satisfaction and safety. They also inform the development of operational procedures and training.