NASA-STD-3001 Technical Brief

Environmental Control & Life Support System (ECLSS): Human-Centered Approach

OCHMO-TB-002
Rev A

Executive Summary

Humans living and working in space contend with a hostile/closed environment that must be monitored and controlled to keep the crewmembers safe and able to perform mission objectives. NASA-STD-3001 provides technical requirements that address the key aspects of the human physiological system that must be accounted for by programs employing human-rated systems. Compliance with requirements may be ensured with the tailored implementation of an Environmental Control and Life Support System (ECLSS). The ECLSS provides clean air and water to crew in a manned spacecraft through artificial means. The ECLSS manages air and water quality, waste, atmospheric parameters, and emergency response systems.

Relevant Technical Requirements

NASA-STD-3001 Volume 2, Rev C

[V2 4015] Aerobic Capacity
[V2 6001] Trend Analysis of Environmental Data
[V2 6002] Inert Diluent Gas
[V2 6003] O2 Partial Pressure Range for Crew Exposure
[V2 6004] Nominal Vehicle/Habitat Carbon Dioxide Levels
[V2 6006] Total Pressure Tolerance Range for Indefinite Crew Exposure
[V2 6007] Rate of Pressure Change
[V2 6150] Barotrauma Prevention
[V2 6008] Decompression Sickness (DCS) Risk Identification
[V2 6009] Decompression Sickness Treatment Capability
[V2 6011] Post Landing Relative Humidity (RH)
[V2 6012] Crew Health Environmental Limits
[V2 6013] Crew Performance Environmental Zone
[V2 6151] Temperature Selectability
[V2 6152] Temperature Adjustability
[V2 7041] Environmental Control
[V2 6017] Atmospheric Control
[V2 6020] Atmospheric Data Recording
[V2 6021] Atmospheric Data Displaying
[V2 6022] Atmospheric Monitoring and Alerting Parameters

Executive Summary (continued)

Related OCHMO Technical Briefs:
1. Carbon Dioxide (CO2)
2. Decompression Sickness (DCS) Risk Mitigation
3. Spaceflight Toxicology Chemical Contaminants
4. Body Waste Management
5. Water – Human Consumption
6. Fire Protection
7. Bone Loss

Relevant Technical Requirements

[V2 6023] Trace Constituent Monitoring and Alerting
[V2 6024] Combustion Monitoring and Alerting
[V2 6025] Contamination Monitoring and Alerting
[V2 6153] Celestial Dust Monitoring and Alerting
[V2 6107] Nominal Vehicle/Habitat Atmospheric Ventilation
[V2 6108] Off-Nominal Vehicle/Habitat Atmospheric Ventilation
[V2 6050] Atmosphere Contamination Limit
[V2 6052] Particulate Matter
[V2 6053] Lunar Dust Contamination
[V2 6059] Microbial Air Contamination
[V2 6026] Potable Water Quality
[V2 6051] Water Contamination Control
[V2 6046] Water Quality Monitoring
[V2 6109] Water Quantity
[V2 6110] Water Temperature
[V2 6039] Potable Water Dispensing Rate
[V2 6040] Potable Water Dispensing Increments
[V2 6047] Toxic Hazard Level Three
[V2 6048] Toxic Hazard Level Four
[V2 6049] Chemical Decomposition
[V2 6060] Biological Payloads
[V2 6061] Environment Cross-Contamination
[V2 6063] Contamination Cleanup
[V2 7020] Body Waste Management Capability
[V2 7025] Body Waste Containment

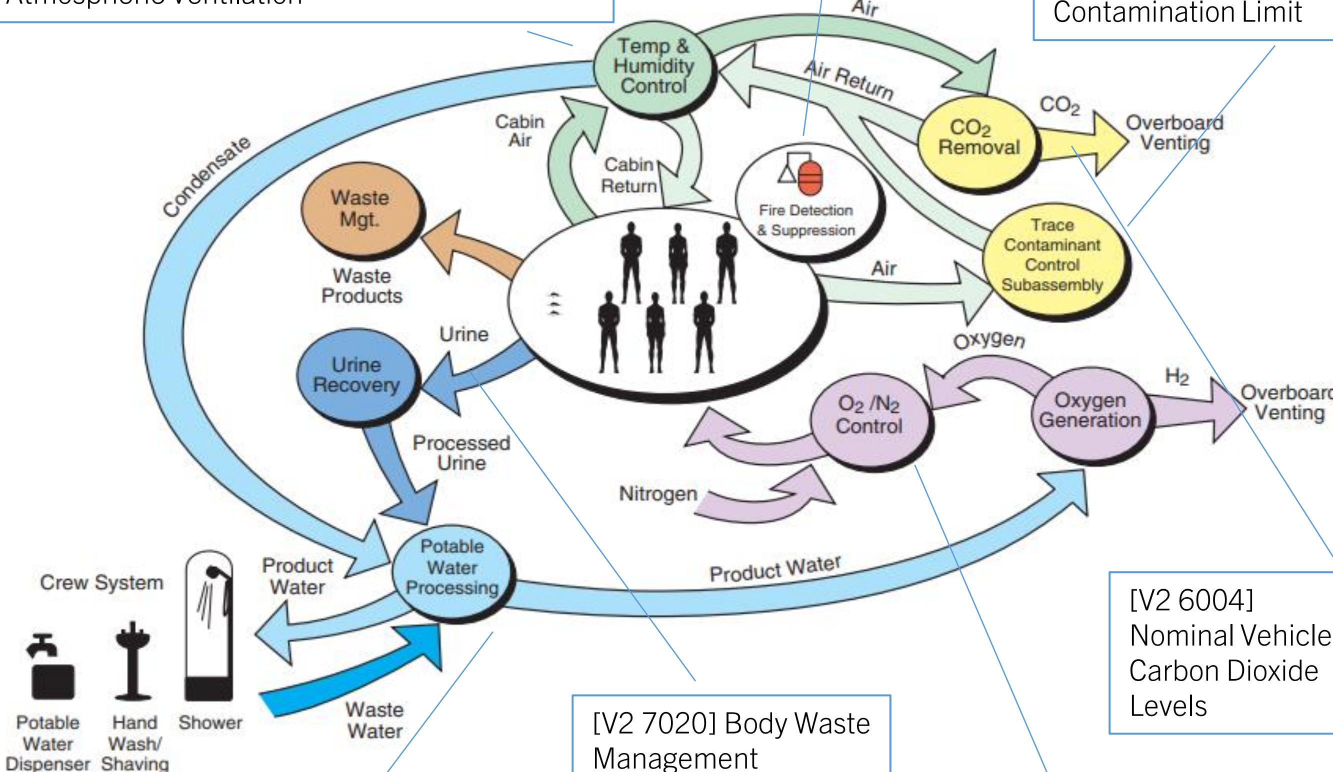
Overview

Environmental Control and Life Support Subsystem Diagram

[V2 6012] Crew Health Environmental Limits
[V2 6013] Crew Performance Environmental Zone
[V2 6107] Nominal Vehicle/Habitat Atmospheric Ventilation

[V2 6024] Combustion Monitoring and Alerting

[V2 6025] Contamination Monitoring and Alerting
[V2 6050 Atmosphere Contamination Limit



[V2 6004] Nominal Vehicle Carbon Dioxide Levels

[V2 7020] Body Waste Management Capability
[V2 7025] Body Waste Containment

[V2 6002] Inert Diluent Gas
[V2 6003] O2 Partial Pressure Range for Crew Exposure
[V2 6006] Total Pressure Tolerance Range for Indefinite Crew Exposure

[V2 6026] Potable Water Quality
[V2 6051] Water Contamination Control
[V2 6109] Water Quantity
[V2 6110] Water Temperature
[V2 6039] Potable Water Dispensing Rate
[V2 6040] Potable Water Dispensing Increments

Background

Human Body Inputs and Outputs

The primary functions of the ECLSS is to provide a healthy, productive living and working environment that can maintain the health of the crew while they live in harsh conditions that would be otherwise uninhabitable due to changes in pressure, temperature, atmosphere, as well as logistics to provide breathable air and water.

<u>Inputs</u>

Food & Nutrition

Average 3,035 kcal/day per crewmember ***[V2 7003]***

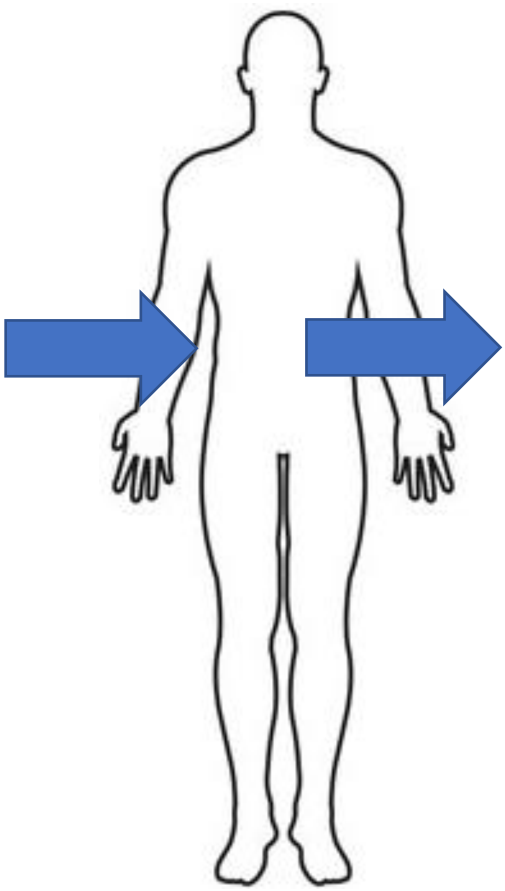
Water

Minimum 2.5 L/day per crewmember ***[V2 6109]***

Gas

$\geq$30% diluent gas ***[V2 6002]***

145-155 O_2 partial pressure (mmHG) normoxia target range ***[V2 6003]***



<u>Outputs</u>

Fecal & Urine

Feces: max average of 2 events of 1.1lb/event per crewmember per day ***[V2 7102]***

Urine: max average of 7 events of 1L/event per crewmember per day ***[V2 7102]***

Liquid

3.870kg/day per crewmember Respiration and Perspiration (combined with urine)

Respiration

Average 1 hour CO_2 partial pressure ($ppCO_2$) $\leq$3 mmHg ***[V2 6004]***

<u>Environmental Regulation</u>

[V2 6012] Crew Health Environmental Limits

Operating Limit: 18°C/75% humidity to 27°C/25% humidity

[V2 6013] Crew Performance Environmental Zone

Operating Limit: 20°C - 25°C and 30-60% humidity

In addition to these guidelines, special considerations must be given to the following:

- Increased O_2 consumption, and increased CO_2, perspiration, and metabolic heat output during crew exercise time.
- Need for extra calories and potable water during EVAs.

Background

Pressure Control System (PCS) Humans receive essential oxygen through respiration, where oxygen (O_2) is taken into the lungs and absorbed in the body, allowing all critical body systems to function. In addition to absorbing O_2, the body releases carbon dioxide (CO_2) and gaseous nitrogen (N_2). The body requires a stable O_2 partial pressure in order to maintain adequate oxygen balance.

PCS functions include:

- Monitor O_2, N_2, and total pressure
- Maintain O_2/N_2 environment pressurized to ranges that are habitable for crew and functional for the cabin air-cooled equipment
- Supply N_2 to pressurize the supply and wastewater tanks
- Supply breathing gas directly to the Launch and Entry Suit (LES) helmets
- Capable of rapid depressurization response if needed

NASA-STD-3001 Technical Requirements for PCS	
3001 Technical Requirement	**ECLSS Function**
[V2 6002] Inert Diluent Gas	Maintain at least 30% diluent gas in the cabin atmosphere to mitigate clinically significant absorption atelectasis.
[V2 6003] O_2 Partial Pressure Range for Crew Exposure	Maintain inspired oxygen partial pressure (P_IO_2) within the given pressure exposure ranges to prevent hypoxia or hyperoxia.
[V2 6006] Total Pressure Tolerance Range for Indefinite Crew Exposure	Maintain the pressure to which the crew is exposed between 26.2 kPa < pressure ≤ 103 kPa (3.8 psia < pressure ≤ 14.9 psia) for indefinate exposure without measureable impairments to health or performance.
[V2 6007] Rate of Pressure Change	For pressure changes >1.0 psi, limit the rate of change of total internal vehicle pressure to 13.5 psi/min or less to prevent injury to crewmembers' ears and lungs during depressurization and repressurization.
[V2 6150] Barotrauma Prevention	Give crew the ability during a commanded pressure change to pause the system within 1 psi of the command being issued and the ability to increase or decrease pressure as needed to avoid discomfort and barotrauma.
[V2 6009] Decompression Sickness Treatment Capability	The system is capable of providing DCS treatment.

Reference the NASA OCHMO DCS Technical Brief and OCHMO-TB-003 Habitable Atmosphere for additional information.

Background

The ECLSS system functions to maintain homeostasis of the crewmembers by managing the atmospheric air composition and pressure make-up. In combination with other requirements that control the cabin atmosphere (i.e., CO_2, ventilation, temperature/humidity, etc.), these ECLSS functions maintain crew health, safety, and overall performance.

Diluent Gas

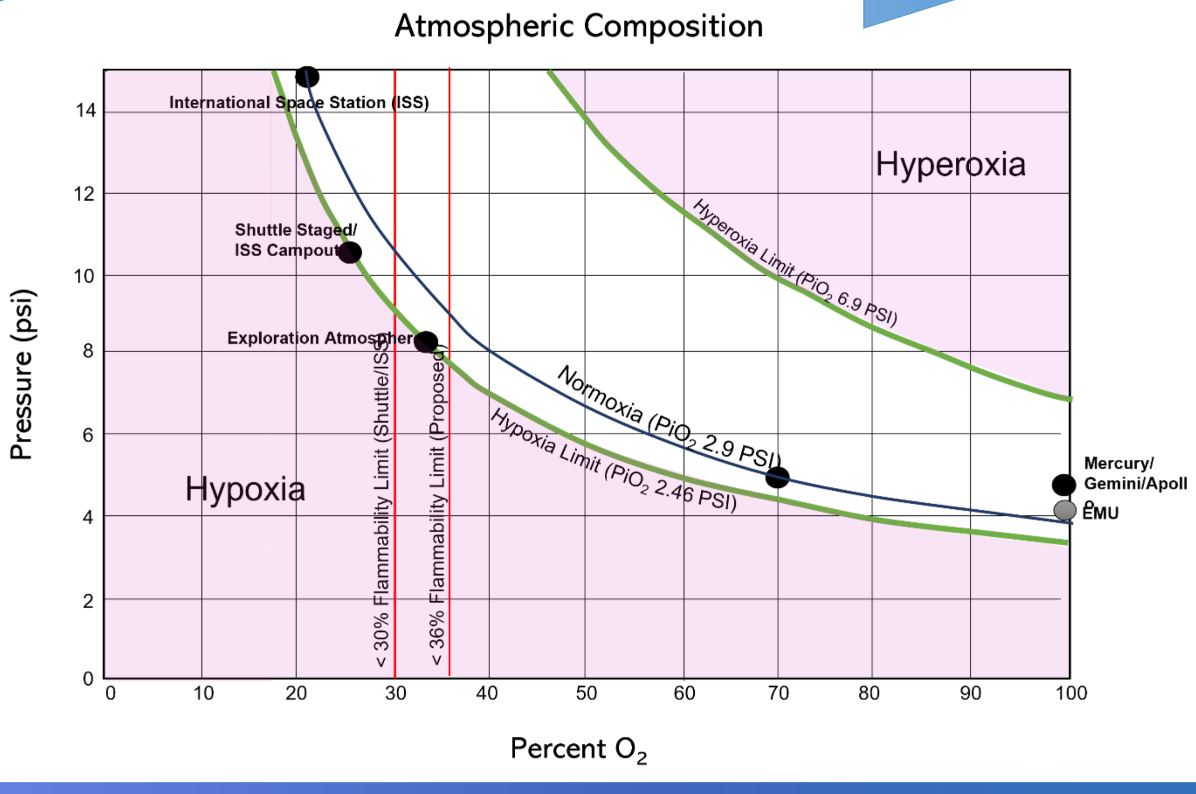
Nominally, the cabin atmosphere must contain at least 30% diluent gas. Measurable oxygen absorption atelectasis occurs with fractions of oxygen above 50%. A diluent gas is required to prevent excessive levels of oxygen absorption atelectasis during prolonged exposures, in addition to reducing the ignition/flammability threshold.

Oxygen

For all systems, the range of ambient dry-gas ppO_2 is to be considered in the context of P_IO_2. Normoxia target range is 145-155 mmHg. This prevents the occurrence of hypoxia or hyperoxia.

Pressure

Total pressure is maintained between 26.2 kPa < pressure ≤ 103 kPa (3.8 psia < pressure ≤ 14.9 psia). During certain spacesuit operations, the crew may be exposed to pressure above or below this range for limited periods of time. Total pressure and rates of pressure change are maintained to prevent decompression sickness and barotrauma symptomatology.



Background

Air Revitalization System (ARS) is responsible for air quality during crewed missions including:
•Control of temperature and humidity
•Air circulation and ventilation
•Removal of CO_2 and trace contaminants
•All associated monitoring

NASA-STD-3001 Technical Requirements ARS	
3001 Technical Requirement	**ECLSS Function**
[V2 6001] Trend Analysis of Environmental Data	System monitors environmental data to perform temporal trend analyses.
[V2 6004] Nominal Vehicle/Habitat Carbon Dioxide Levels	Limits average one-hour CO_2 partial pressure ($ppCO_2$) in the habitable volume to no more than 3 mmHg.
[V2 6012] Crew Health Environmental Limits	Maintain cabin humidity and temperature within the defined operating limits to protect for crew health.
[V2 6013] Crew Performance Environmental Zone	Enable the system to reach defined cabin humidity and temperature levels to support crew comfort and performance.
[V2 6107] Nominal Vehicle/Habitat Atmospheric Ventilation	Maintains ventilation rate within atmosphere to provide adequate circulation to prevent CO_2 and thermal pockets from forming.
[V2 6108] Off-Nominal Vehicle/Habitat Atmospheric Ventilation	Controls for ppO_2, $ppCO_2$ and relative humidity during off-nominal operations.
[V2 6021] Atmospheric Data Displaying	System displays real-time values for pressure, humidity, temperature, ppO_2, and $ppCO_2$.
[V2 6022] Atmospheric Monitoring and Alerting Parameters	System alerts the crew locally and remotely when atmospheric parameters are outside safe limits (including pressure, humidity, temperature, ppO_2, and $ppCO_2$).
[V2 6024] Combustion Monitoring and Alerting	System monitors in real-time for toxic atmosphere components that would result from pre-combustion and combustion events.
[V2 6025] Contamination Monitoring and Alerting	System monitors and displays atmospheric compound levels.
[V2 6050] Atmosphere Contamination Limit	Limits gaseous pollutant accumulation in the habitable atmosphere to below chemical concentration limits specified in JSC-20584, Spacecraft Maximum Allowable Concentrations for Airborne Contaminants (SMACs).

Background

Temperature and Humidity

NASA-STD-3001 levies two technical requirements related to the atmospheric environment:

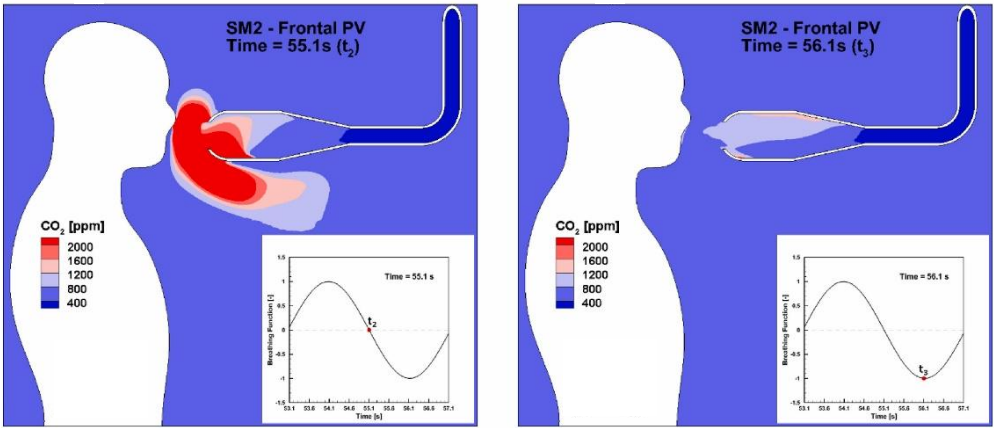
- [V2 6012] provides environmental parameters that keeps the internal habitat at safe levels of temperature and humidity for protection of crew health. 18℃ - 27℃ and 25-75% humidity
- [V2 6013] provides environmental parameters that take into consideration crew performance, specifying temperature and humidity limits in which humans can achieve thermal comfort and not have their performance of routine activities affected by thermal stress. 20℃ - 25℃ and 30-60% humidity

Due to individual variability among crewmembers and the likelihood of different crewmembers performing different tasks at different metabolic rates, it is necessary to have the capability to change temperature set points, adjust localized air flow, and/or have various clothing options available to achieve thermal comfort for all crew.

Air Circulation and Ventilation

Fans and appropriate ventilation are important to mix atmospheric gases and decrease risk of pockets or overexposure to any gas. Due to lack of natural convection in microgravity, spacecrafts may develop areas with low atmospheric circulation, which could result in a localized area of increased CO_2. Some special considerations for the design of ventilation systems include:

- Exercise station – Exercise areas need increased airflow to facilitate heat transfer and relieve sweat accumulation.
- Sleeping station – Individually adjustable airflow controls for comfort and prevention of CO_2 pockets.
- Eating station – Airflow should not blow loose morsels of food away from crewmembers.
- Maintenance areas – Crewmembers may perform maintenance behind a panel in an area not part of the nominal habitable volume and therefore does not have ventilation.



Reference the NASA HIDH for additional information on air circulation and ventilation.

Interaction of breath dynamics and the personalized ventilation (PV) diffuser for case SM2 (frontal PV solution) in median plane at end of exhalation (left chart) and end of inhalation (right chart)

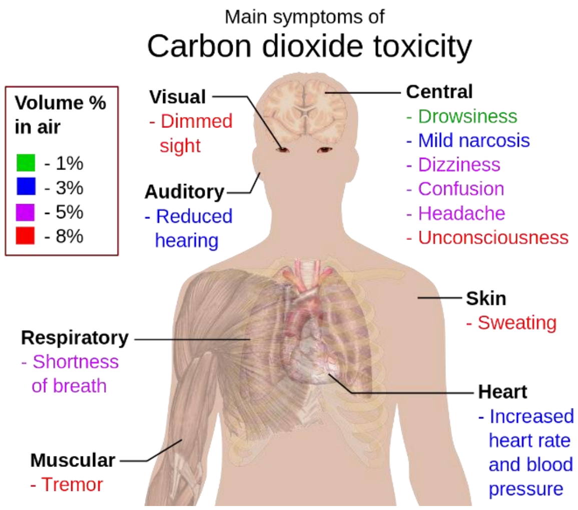
From: Georgescu et al. (2021) *Personalized ventilation solutions for reducing CO_2 levels in the crew quarters of the International Space Station*

Findings: A personalized ventilation diffuser in close proximity to the breathing zone reduces inhaled CO_2

Background

Removal of CO_2 and Trace Contaminants

Humans on spacecraft vehicles are the main contributors to atmospheric CO_2 levels. Crewmembers inhale the ECLSS-provided safe breathable air and exhale CO_2, which is removed from the atmosphere by a carbon dioxide removal process designed to maintain the cabin atmosphere within safe ranges. If CO_2 levels become too elevated, the crewmembers may begin to experience adverse effects (see graphic below and CO_2 technical brief for additional information).




Portable breathing apparatus

In addition to the removal of CO_2 from the atmosphere, toxic chemicals must also be monitored for and removed via the ECLSS. The crew may be exposed to chemicals from a variety of sources including compounds used in the system, payload chemicals, off-gassed products, batteries, products of corrosion, external contaminants, hardware failures and repairs, and thermal degradation of electronic components. NASA toxicologists establish guidelines for safe and acceptable levels of individual chemical contaminants in spacecraft air (SMACs) to provide guidance on allowable chemical exposures during nominal operations and emergency situations.

Reference the NASA OCHMO CO_2 Technical Brief for additional information.

Atmospheric Monitoring and Alerting

Air monitoring gives the crew and ground support personnel access to important data regarding the atmospheric composition of the spacecraft breathable atmosphere. This in turn provides the capability of automatic alerts or alarms when levels are outside of the required ranges set by SMACs so that crew may respond appropriately Some targeted monitoring systems of the ECLSS includes:

- Combustion Product Monitor (CPM)
- Carbon dioxide monitor (CDM)
- Air quality monitor (AQM)

Reference the NASA OCHMO Spaceflight Toxicology Technical Brief for additional information.

Background

ECLSS Adaptation – Exercise and Nutrition Example

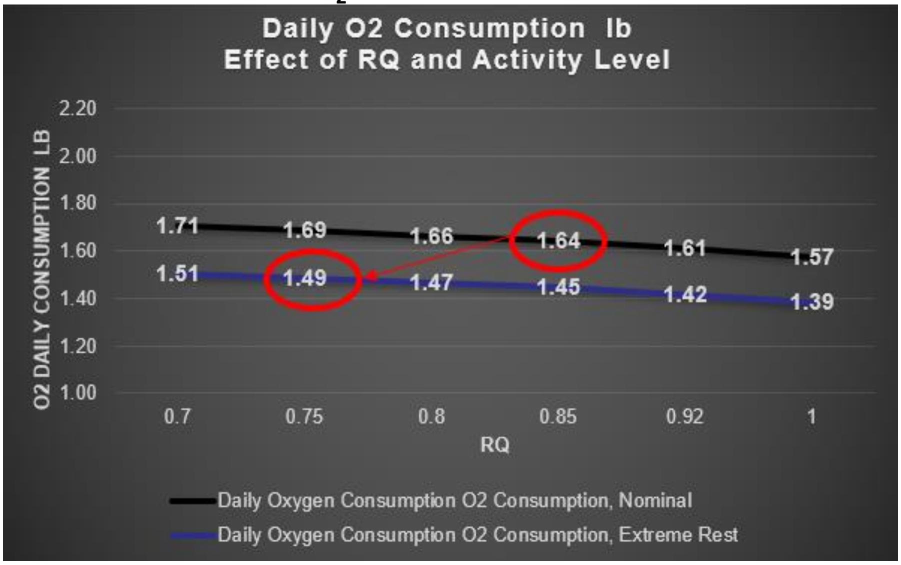
The ECLSS must be able to adapt to constantly changing atmospheric demands created by changes in crew number and composition as well as changes in crew activity. During exercise, crewmembers increase O_2 consumption and CO_2 output. The ECLSS must be designed to handle the increased need for oxygen and CO_2 scrubbing during exercise times. The O_2 and CO_2 levels are also affected by changes in diet makeup (i.e., amount of calories, fat, and carbohydrates consumed). To reduce O_2 consumption, activity level must be reduced. To reduce CO_2 production, reduce activity and the Respiratory Quotient (RQ) by modifying the diet.

O_2 Variables: 5ml/kg/min (resting energy expenditure). 75 kg average person weight. 120 minutes of exercise (at 65% average VO_2 max= 45ml/kg/min).

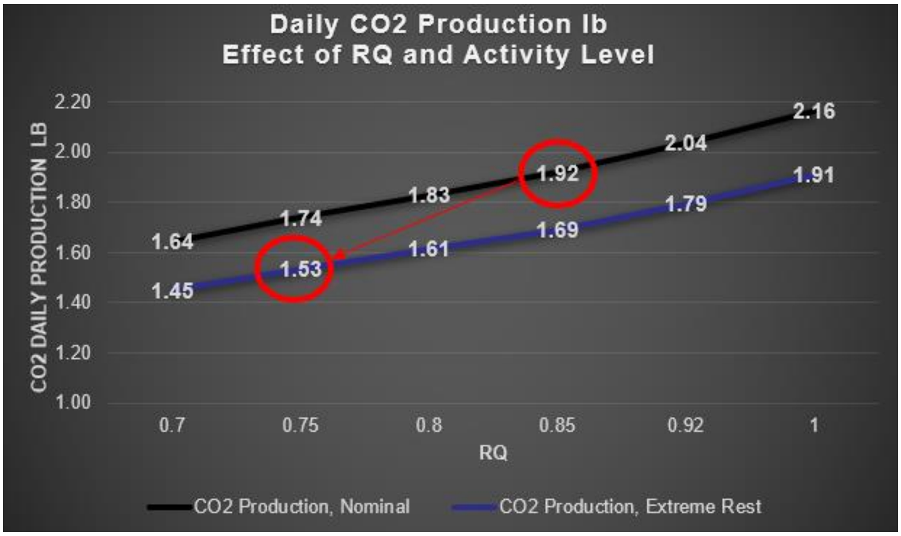
For example crew of 7 astronauts:

a. Resting oxygen consumption - 0.771 kg/person/day
b. Oxygen consumption during exercise - additional 0.376 kg/person/exercise session
c. Daily oxygen consumption (with exercise) - 1.083 kg/person/day
d. Total Oxygen consumption with no exercise - 5.397 kg O_2/day
e. Total Oxygen consumption with exercise - 7.581 kg O_2/day
f. Need additional 2.184 kg O_2/day with exercise activity

O_2 Reduction of 10%



CO_2 Reduction of 20%



CO_2 Variables: 20 Kcal/Kg/diet composed of 40% fat and 20% carbohydrate diet to create an RQ of 0.85.

a. Assuming a mixed diet and RQ of 0.85, crew weight of 75 kg, the Volume of CO_2 produced assuming a 2,000 calorie diet is 350 Liters/per person/per day.
b. Assuming a mixed diet and RQ of 0.85, crew weight of 75 kg, the Volume of CO_2 produced assuming a 1,500 calorie diet is 262 Liters/per person/per day.
c. Assuming a mixed diet and RQ of 0.85, crew weight of 75 kg, the Volume of CO_2 produced assuming a 1,000 calorie diet is 175 Liters/per person/per day.

Background

Water Management

Astronauts need approximately 2.5 L of potable water for hydration per crewmember per day. Additional potable water is allotted for hygiene, medical use, eye irrigation, EVA operations, and reentry loading as well as crew recovery. Water's launch mass is prohibitive for transfer into space and its limited supply makes recycling vital for exploration beyond low-earth orbit. To meet this challenge, in addition to transporting water from ground, the ISS utilizes a system that can recycle up to 90% of the fluid captured from hygiene and other activities on the ISS from the atmosphere into potable water.

In addition to providing the needed amount of microbiologically safe potable water to each crewmember, the system must also ensure that the water is aesthetically acceptable by the crew in terms of taste and smell. Special consideration should be taken with treatment chemicals and residual biocides. For example, at effective biocidal levels iodine can alter the aesthetics of the water as well as cause iodine-related illness.

NASA-STD-3001 Technical Requirements for WRS	
3001 Technical Requirement	**ECLSS Function**
[V2 6026] Potable Water Quality	System provides crew with aesthetically acceptable potable water that is chemically and microbiologically safe for humans.
[V2 6051] Water Contamination Control	Prevents potable and hygiene water supply from becoming contaminated.
[V2 6109] Water Quantity	System provides a minimum, water quantity for expected needs of the mission as defined in NASA-STD-3001.
[V2 6110] Water Temperature	System provides appropriate water temperature as defined in NASA-STD-3001.
[V2 6039] Potable Water Dispensing Rate	Water is dispensed at a rate compatible with the food system.
[V2 6040] Potable Water Dispensing Increments	Water is dispensable in specified increments compatible with the food system to prevent overflow.

Contributors to Water Quality:

- Humidity condensate and urine
- Added biocides
- Microbial and biofilm
- Off-gassing/leaching of materials
- Mission duration
- Trace contaminants

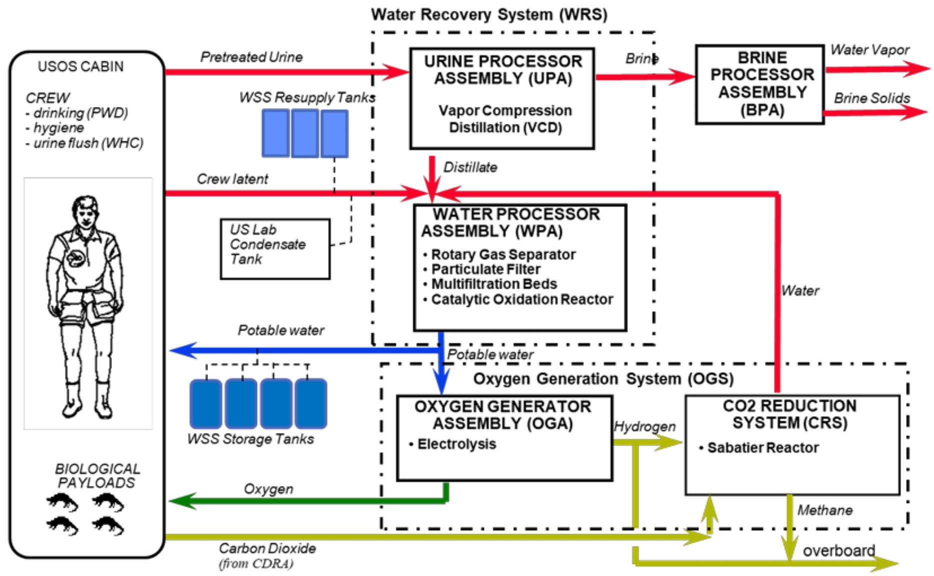
Reference the NASA OCHMO Water Technical Brief for additional information.

Background

Calcium deposits affect Urine Processing Assembly (UPA)

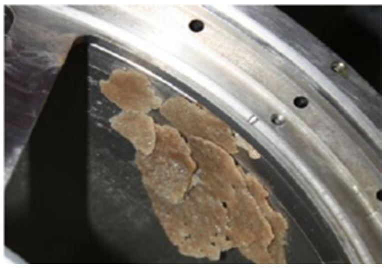
The UPA's distillation assembly helps transform urine from crew members into usable water.

With its initial use, the distillation assembly struggled with calcium sulfate build-up in the processing unit. Due to microgravity induced bony turnover, there is an increase in urinary calcium excretion leading to buildup of calcium sulfate in the UPA that interfered with successful hardware functioning. The distillation and processing procedure was changed and the water recovery rate was reduced to prevent the precipitation causing the buildup, then the pretreat chemicals were changed to allow for a higher water recovery rate. The new Brine Processing Assembly (BPA) allowed for the recovery of >90% of water.



Source: Williamson, Wilson, & Gleich (2022). Status of ISS Water Management and Recovery

Reference the NASA OCHMO Bone Loss Technical Brief for additional information.



Urine calcium deposits in UPA of ISS

Increased Risk of Renal Stones

Calcium in the urine not only caused problems with the UPA equipment, but concern was raised regarding the potential for renal stone development due to increased urine calcium concentrations. Renal stones are associated with debilitating pain, blockage of the ureter, kidney infections, and kidney damage. NASA continues to study ways to decrease the risk of renal stones.

Renal Stone Countermeasures

- Increase water intake, as dehydration can increase renal stone risk.
- Pharmaceuticals including potassium citrate, which can decrease stone formation, and bisphosphonates to decrease bone breakdown.
- Exercise to decrease bone loss.
- Ultrasounds are being studied to move or breakdown stones if they do occur.

[V2 6109] Water Quantity The system **shall** provide a minimum water quantity as specified in Table 4, Water Quantities and Temperatures (NASA-STD-3001 Volume 2) for the expected needs of each mission, which should be considered mutually independent.

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

Background

ECLSS Fire Detection and Suppression

The Fire Detection and Suppression subsystem provides fire detection sensors for the Station, fire extinguishers, portable breathing equipment, and a system of alarms and automatic software actions to alert the crew and automatically respond to a fire. Similar systems are required on all crewed vehicles.

Fire Detection and Suppression (FDS) – U.S. Modules

- Each module equipped with detectors and alarms that alert the crew of a potential fire event
    - Fire detectors detect smoke through laser-based scatter/obscuration detection
- Fire suppression performed by applying CO_2 with a portable fire extinguisher tank – CO_2 was elected as the primary fire suppression agent on ISS based on its compatibility with the ECLSS design to remove excess CO_2 from the atmosphere
- Other types of fire extinguishers include water mist extinguishers and fire cartridges
- Two fire extinguishers located in each module and two Portable Breathing Apparatuses (PBAs) that dispense oxygen available in each module to support crew during fire emergencies
- Combustion Product Monitor (CPM) laser absorption spectrometer measures ambient gas phase concentrations of CO, HCl, HCN, HF, and CO_2.

During and after a fire event, contaminant readings are taken frequently (several per hour). This frequent sampling allows the crew and ground to have insight into whether contaminant levels are quickly rising and approaching (or at) levels requiring masks to be donned. These measurements are necessary to ensure that the crew does not experience acute exposure to contaminants that may pose a risk to crew health.

Portable fire extinguishers

NASA-STD-3001 Technical Requirements for FDS

3001 Technical Requirement	ECLSS Function
[V2 6024] Combustion Monitoring and Alerting	System monitors in real-time for toxic atmosphere components that would result from pre-combustion and combustion events.

Reference the NASA OCHMO Fire Protection Technical Brief for additional information.

Application

Future Exploration Considerations

Multi-Mission Space Exploration Vehicle (MMSEV)

An ECLSS design for the MMSEV is currently under development. A rudimentary fluid schematic was developed during the Constellation Lunar Surface Systems Program for a surface rover's flight ECLSS. This schematic was implemented and improved upon and now encompasses a vehicle that supports micro gravity, planetary, and lunar missions. Contingencies considered during these iterative design cycles are feed the leak and depress/repress cycle of the cabin atmosphere in case of fire, and a rescue of crew with a 72-hour duration to the base/lander.

Current Parts of the MMSEV ECLSS:

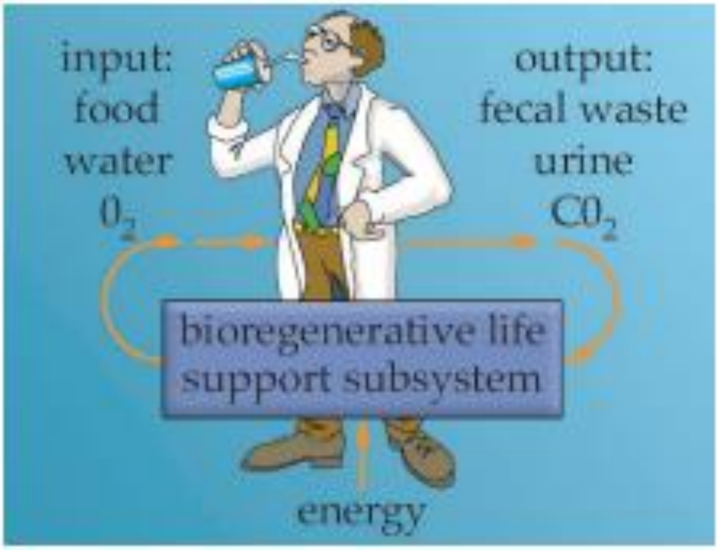
- Pressure Control System (PCS) - regulates cabin total pressure and constituent partial pressures
- Air Revitalization System (ARS) – provides cabin air circulation and thermal control. Trace contaminant control, CO2 scrubbing, recuperates moisture, and atmospheric monitoring
- Waste Control System (WCS) – collects and stores human metabolic waste and food and packaging waste
- Potable Water System (PWS) – dispenses both hot and cool potable water for drink and meal preparations and hygiene

For additional information: Stambaugh et al. (2013). Environmental Controls and Life Support System (ECLSS) Design for a Multi-Mission Space Exploration Vehicle (MMSEV). 43rd International Conference on Environmental Systems. https://doi.org/10.2514/6.2013-3428

Closed-Loop Life Support

For future long-term missions to the Moon or Mars, lasting months to years, it won't be practical to bring all the required supplies or rely on re-supply. Thus, there is a need to establish a closed loop system that can reclaim and recycle water and other wastes. This type of system could recycle feces, urine, and CO_2 to provide water and food to the crew and greatly reduce the mass needed to pack enough supplies for long-duration missions.

For additional information: Environmental Control and Life-support Subsystem (ECLSS). Chapter 4.4.1.



Bioregenerative Life-support Subsystems: For long space missions to Mars or beyond, bioregenerative life support sub-systems may be needed. These systems allow us to "close the loop" and recycle all human waste into food, water, and oxygen.

Back-Up

Major Changes Between Revisions

Original → Rev A

- Added information regarding exercise, oxygen intake, and carbon dioxide output.

Reference Information

History of ECLSS			
Space Vehicle	ECLSS Parameters	Potable Water System	Water Cleaning
Mercury	• Pressure suit revitalize atmosphere supply, control crew temp/humidity • Cabin control cabin ventilation, temperature, atmospheric pressure	• Pre-filled ground supplied 2.5 kg water pouch with , water transferred from water pouch to crew with drink tube, delivered on demand by squeezing pouch	• Local ground disinfection of source water, no additional biocide added
Gemini	• Mercury cabin/suit system with added: • Weight and power reducing oxygen storage, integrated heat exchange/water separator • Modular construction ECLSS components	• First attempt (unsuccessful), to use fuel cell-produced water, • Used fill and draw with ground supplied water • Water stored in bladder tanks • Water gun delivered water to crew	• Chlorine supplied prior to launch
Apollo	• Mercury Cabin/suit system • Two separate systems: Crew module & Lunar life support • Service module water and electricity • Safer 60%/40% oxygen/nitrogen cabin gas mixture	• Potable water from fuel cells and oxygen supplied from service module • Lunar module used to fill and draw as no fuel cells available	• Crew module used chlorine with additional sodium hypochlorite • Lunar module used Iodine
Skylab	• Two-level Airlock module • Stored water and oxygen • Regenerable molecular sieve for $C0_2$ and humidity removal • Mixed oxygen/nitrogen atmosphere • Ultraviolet fire detectors	• Fill and draw system design. • System contained equipment for storage, microbial control, and distribution of water • Water provided to service the life support umbilical's, pressure control units, and fire hose. • Multiple water tanks throughout vehicle	• Iodine including a water purification system to sample iodine level in tanks
Shuttle	• Pressure control, fire control, air revitalization, active and passive thermal monitoring • Lithium oxide air revitalization • Thermal freon loop	• Water is supplied via fuel cells following passage through a hydrogen separator	• Iodine disinfection via microbial check value (MCV)

Reference Information

Spacesuit - Extravehicular Mobility Unit (EMU) Portable Life Support System (PLSS)
When a crewmember is preforming a spacewalk, the spacesuit is essentially an independent spacecraft with its own ECLSS system, called the PLSS. The PLSS provides pressure control, atmosphere revitalization, and thermal control in order to maintain a comfortable habitable environment for the crewmember. The PLSS maintains a pure O_2 atmosphere at approximately 4.2 psi which provides high enough ppO_2 for respiration while low enough to not cause restrictions on crew motion.

PLSS Functions:

- Supplies oxygen for breathing and suit ventilation
- Removes CO_2 via Lithium Hydroxide (LiOH) or METOX cartridge, contaminants, and humidity from suit atmosphere
- Provides thermal control through water coolant loop circulating through Liquid Cooling Ventilation Garment (LCVG) into PLSS where heat is rejected via sublimator
- LCVG is worn under the spacesuit to cool the crewmember, with water traveling through tubing to help regulate temperature
- Regulates suit pressure
- Monitors astronaut health and critical suit parameters

PLSS Primary Subsystems:

Primary oxygen supply: supplies oxygen for breathing and pressurizes the suit and helmet

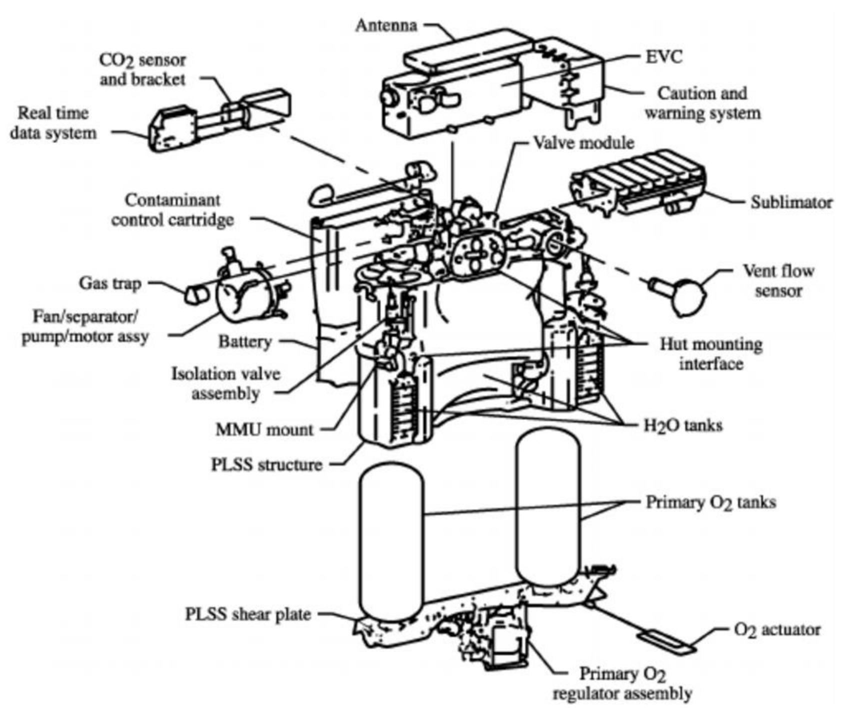
Oxygen ventilation: circulates oxygen through the spacesuit pressure garment and purifies recirculating oxygen, helps to cool astronaut by evaporating moisture that accumulates on skin

Liquid transport loop: water enters the system and circulates chilled water through network of plastic tubing integrated in the LCVG then travels through the sublimator where heat is removed and cooled water is used to cool the fan motor before returning to the LCVG.

Feedwater loop: supplies expendable water to sublimator for cooling; water passed through the sublimator which absorbs system heat and discharges hot water to the outside

Electrical power subsystem: provides electrical power to fan and pump motor assemblies

Emergency Supplemental Oxygen system (SOP): supplies additional 30-90 minutes of oxygen if Primary Oxygen System fails



Referenced Technical Requirements

NASA-STD-3001 Volume 2 Revision C

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

[V2 6001] Trend Analysis of Environmental Data The system shall provide environmental monitoring data in formats compatible with performing temporal trend analyses.

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

[V2 6003] O_2 Partial Pressure Range for Crew Exposure The system shall maintain inspired oxygen partial pressure (PIO2) in accordance with Table 1, Inspired Oxygen Partial Pressure Exposure Ranges.

[V2 6004] Nominal Vehicle/Habitat Carbon Dioxide Levels The system shall limit the average one-hour CO2 partial pressure (PICO2) in the habitable volume to no more than 3 mmHg.

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

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

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

[V2 6008] Decompression Sickness (DCS) Risk Identification Each program shall define mission-unique DCS mitigation strategies to achieve the level of acceptable risk of DCS as defined below within 95% statistical confidence: a. DCS ≤ 15% (includes Type I or isolated cutis marmorata). b. Grade IV venous gas emboli (VGE) ≤ 20%. c. Prevent Type II DCS.

[V2 6009] Decompression Sickness Treatment Capability The system shall provide DCS treatment capability.

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

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

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

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

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

Referenced Technical Requirements

[V2 7041] Environmental Control The system environmental control shall accommodate the increased O2 consumption and additional output of heat, CO2, perspiration droplets, odor, and particulates generated by the crew in an exercise area.

[V2 6017] Atmospheric Control The system shall allow for local and remote control of atmospheric pressure, humidity, temperature, ventilation, and ppO2.

[V2 6020] Atmospheric Data Recording For each isolatable, habitable compartment, the system shall automatically record pressure, humidity, temperature, ppO2, and ppCO2 data continuously.

[V2 6021] Atmospheric Data Displaying The system shall display real-time values for pressure, humidity, temperature, ppO2, and ppCO2 data to the crew locally and remotely.

[V2 6022] Atmospheric Monitoring and Alerting Parameters The system shall alert the crew locally and remotely when atmospheric parameters, including atmospheric pressure, humidity, temperature, ppO2, and ppCO2 are outside safe limits.

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

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

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

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

[V2 6107] Nominal Vehicle/Habitat Atmospheric Ventilation The system shall maintain a ventilation rate within the internal atmosphere that is sufficient to provide circulation that prevents CO2 and thermal pockets from forming, except during suited operations, toxic cabin events, or when the crew is not inhabiting the vehicle.

[V2 6108] Off-Nominal Vehicle/Habitat Atmospheric Ventilation The system shall control for ppO2, ppCO2, and relative humidity during off-nominal operations, such as temporary maintenance activities in areas not in the normal habitable volume.

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

[V2 6052] Particulate Matter The system shall limit the habitable atmosphere particulate matter concentration for total dust to <3 mg/m3 with a crew generation rate of 1.33 mg/person-minute, and the respirable fraction of the total dust <2.5 µm (micrometer) in aerodynamic diameter to <1 mg/m3 with a crew generation rate of 0.006 mg/person-minute.

Referenced Technical Requirements

[V2 6053] Lunar Dust Contamination The system shall limit the levels of lunar dust particles less than 10 µm in size in the habitable atmosphere below a time-weighted average of 0.3 mg/m3 during intermittent daily exposure periods that may persist up to 6 months in duration.

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

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

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

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

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

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

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

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

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

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

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

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

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

Referenced Technical Requirements

[V2 6063] Contamination Cleanup The system shall provide a means to remove or isolate released chemical and biological contaminants and to return the environment to a safe condition.
[V2 7020] Body Waste Management Capability The system shall provide the capability for collection, containment, and disposal of body waste for both males and females.
[V2 7025] Body Waste Containment The system shall prevent the release of body waste from the waste management system.

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