NASA-STD-3001 Technical Brief

Microbiology in Spaceflight Overview

OCHMO-TB-046
Rev A

Relevant Technical Requirements

NASA-STD-3001 Volume 1, Rev C
[V1 3002] Pre-Mission Preventive Health Care
[V1 3004] In-Mission Medical Care

NASA-STD-3001 Volume 2, Rev D
[V2 6026] Potable Water Quality
[V2 6046] Water Quality Monitoring and Alerting
[V2 6051] Water Contamination Control
[V2 6059] Microbial Air Contamination Prevention
[V2 6060] Biological Payloads
[V2 6061] Environment Cross-Contamination
[V2 6063] Contamination Cleanup
[V2 7007] Food Microorganism Levels
[V2 7008] Food Preparation
[V2 7009] Food Preparation and Cleanup
[V2 7010] Food Contamination Control
[V2 7015] Food System Cleaning and Sanitizing
[V2 7016] Personal Hygiene Capability
[V2 7020] Body Waste Management Capability
[V2 7025] Body Waste Containment
[V2 7029] Body Waste Management
[V2 7064] Trash Accommodation
[V2 7081] Microbial Surface Contamination
[V2 7082] Surface Material Cleaning
[V2 7083] Cleaning Materials
[V2 7111] Food Safety
[V2 7112] Food Production Facility
[V2 11125] Suit Materials Compatibility
[V2 11126] Suit Materials Cleanability

Executive Summary

Microbial contamination in spacecraft environments poses risks to both crew health and onboard systems. Through the preflight Health Stabilization Program (HSP) and inflight cleanliness procedures aboard the ISS, there has not been a case of infections disease during flight. Implementing effective microbial control practices are crucial for long-term human operation in space. Specific measures are recommended for preventing crew and life-support system contamination, by adhering to human exposure limits and technical requirements, as well as developing deployable microbial control and disinfection strategies.

ESA Astronaut shows the Touching Surfaces experiment, which will guide the design of antimicrobial surfaces for future space habitats. *NASA, Photo ID: iss066e083048*

Background

Human exposure to microbes is inevitable during spaceflight. This includes many that are part of the human microbiota which are beneficial when in proper balance. However, when these or other microbes are out of balance and proliferate in an uncontrolled manner, there can be significant medical consequences. Improving our comprehension of the ways in which microbes disperse, survive, and multiply in confined indoor spaces contributes to the development of more effective strategies for monitoring, managing, and controlling microorganisms. When applied to spaceflight, this positively affects the health and performance of the crew. This technical brief focuses on medically significant bacteria, viruses, and fungi as assessed by the Microbiology Laboratory at JSC which could be encountered in space.

The historical preventative approach has generally been sufficient, though astronauts have still occasionally contracted infectious diseases. Many contamination control practices which are effective on Earth, such as proper sanitization and hygiene, work well in space.

Current environmental monitoring of microbes using traditional culture-based methods has proven accurate and useful but requires sample return for microbial identification. Improved onboard technologies aimed at detecting, quantifying, and identifying the presence of target organisms are being investigated. The ability to monitor microbial contamination by rapid, simple, and autonomous means will be increasingly important as humans venture further from Earth.

Reference the NASA OCHMO-TB-033 Spaceflight Experience and Medical Care Technical Brief for additional information.

Additional Resources to Reference

Space Station 101: Microbiology

Space Station Microbiology Video

Houston, We Have a Podcast: Interview with Dr. Sharmila Bhattacharya

Risk of Adverse Health Effects Due to Host-Microorganism Interactions

Risk of Adverse Health Event Due To Altered Immune Response

Reference Data

Sample of fungal contamination isolated from ISS air when no HEPA filter was installed.
Microbiology of Human Spacecraft Environments

<u>Habitat Microbes: Air, Water, and Surfaces</u>

- Microbial growth in air and water, and on surfaces should be limited for the safety of crew and performance of habitat systems.
- Prolonged microgravity and space environment-related stresses can alter the immune response, impacting the astronaut's ability to fight an infection. This could allow weak microbes to become medically significant, increasing potential health risk for the crew.
- Environmental conditions also affect virulence (the ability of a microbe to cause disease or illness) and can affect growth kinetics and biofilm formation.

Air

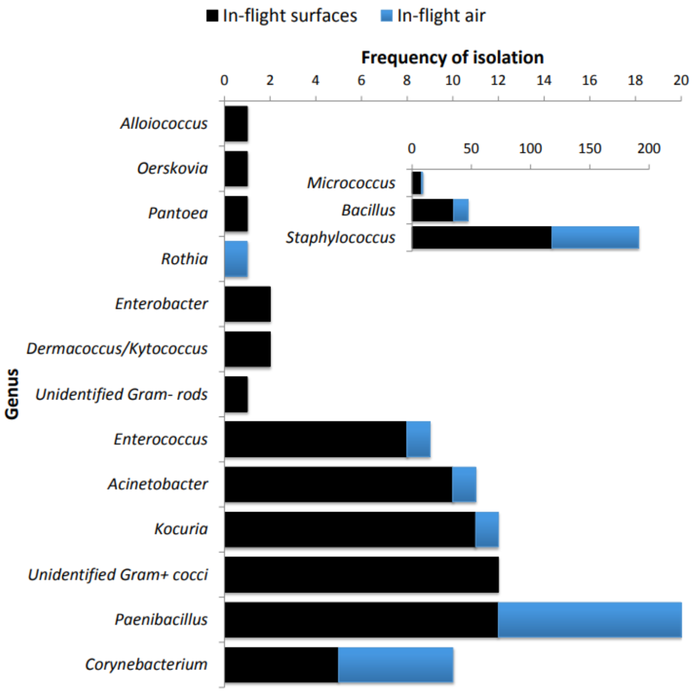
- Aerosols are created from speaking, coughing, or sneezing remain airborne in microgravity, so an air filtration system is crucial.
- Microbial limits for breathing air are designed to prevent infection and allergic response.

HEPA filter on ISS.
Microbiology of Human Spacecraft Environments

- On the ISS:
    - High-efficiency particulate air (HEPA) filtration is required for the air system.
    - The Air Revitalization System of the environmental control and life support system (ECLSS) provides cabin air circulation, thermal control, and trace contaminant control, including filtering of microbial contaminants.
    - Humidity is managed with a condenser and recycled into the potable water system.
    - Charcoal-based air filters replaced the original HEPA filters in Node 1 of the ISS for ~2.5 years to decrease cabin air concentrations of siloxanes. Due to high fungal counts, these filters were replaced with HEPA filters in 2017. Currently, the ISS air filter units combine activated carbon and HEPA filtration.

Reference Data

Various microbes have been identified from environmental monitoring of the air and surfaces of the ISS. These bar graphs illustrate isolates categorized by genera and relative abundance (Pierson 2012). Figures were originally published for NASA in 2018.



The abundance of **bacterial** strains isolated from air and surfaces from the International Space Station environment during flight.

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

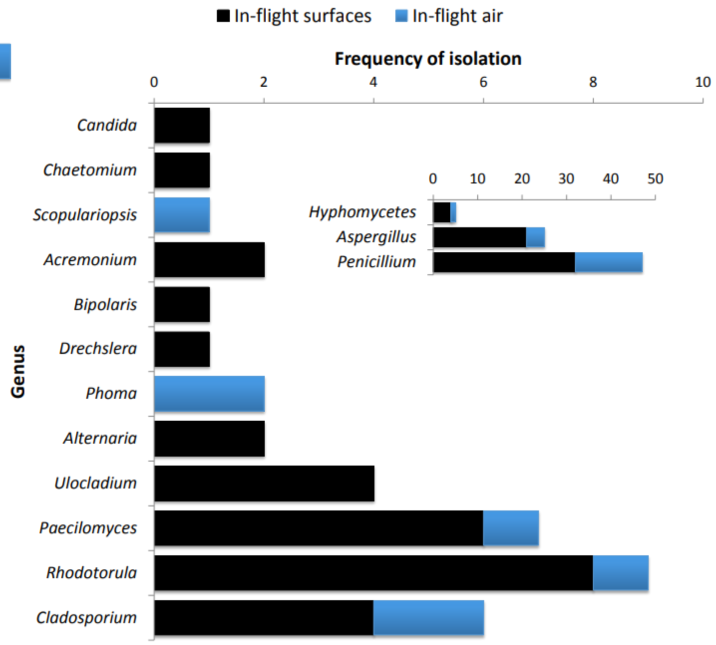
[V2 6059] Microbial Air Contamination
The system shall provide air in the habitable atmosphere that is microbiologically safe for human health and performance.

NASA-STD-3001 Volume 2 Revision D

[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.

NASA-STD-3001 Volume 2 Revision D

Biofilm formation within ISS components. Biofilms in tubing are extremely difficult to remove completely, and easily regrow after tubing is cleaned. Replacing components in space is not always feasible.
NASA



The abundance of **fungal** strains isolated from air and surfaces from the International Space Station environment during flight.

Reference Data

During Expedition 9 in 2004, wet towels hung against fabric panels in the Russian module of the ISS caused mold growth. (Yamaguchi 2014)

Surfaces

All surface materials must be cleanable and compatible with cleaning methods. A human spaceflight program must consider:

- Surfaces materials selection (**[V2 7082] Surface Material Cleaning** and **[V2 7081] Microbial Surface Contamination**)
- Suit materials (**[V2 11125] Suit Materials Compatibility** and **[V2 11126] Suit Materials Cleanability**)
- Cleaning products that are effective yet safe to the crew and materials (**[V2 7083] Cleaning Materials**)

Fungal contamination of the fabric of a Contingency Water Container bag

A microbial culture slide with a sample of a surface in the ISS

Fungal contamination on ISS panels caused by hygiene activities

NASA, Microbiology of Human Spacecraft Environments

Water

- Microbial contamination of water is harmful to both water systems and crew.
- Possible sources of contamination include:
  - Debris/microbes introduced during processing
  - Airborne microbes in flight
  - Human processes in flight
  - Contamination of compounds/materials purposefully added to treat water (iodine & silver as biocides, minerals for dietary purposes and taste enhancement)
  - Contamination of the ground-supplied water
- Humidity in the air must be removed by a condenser to mitigate microbial growth
- Very low levels of microorganisms have been maintained in ISS potable water recycled from wastewater using a combination of a catalytic oxidizer (267°F for 10 minutes), iodine disinfection, and passage through a 0.2-micron filter in the Water Processor Assembly component of the Water Recovery System *NASA 2014, "Status of ISS Water Management and Recovery."*

Reference the NASA OCHMO-TB-002 Environmental Control & Life Support System (ECLSS) Brief for additional information.

Reference Data

Space Food Systems Laboratory
NASA, Photo ID: jsc2012e131116

Crew Microbes: Food, Skin, and Waste

Food Preparation

In accordance with practices on Earth, food should be prepared with safe practices to prevent the spread of pathogens that cause food-borne illnesses.

- The FDA Food Code provides information on minimum temperatures and times for cooking, packaging, freezing, and reheating food.
- See the FDA CORE 2022 Annual Report and the FDA Bad Bug Book for more information on microbes that cause the leading food-borne illnesses in the world. (E.g. produce was the leading cause of food-borne illnesses in 2022.)
- The Space Food Systems Laboratory is responsible for testing, preparing, and packaging food and drink for delivery to the ISS, and meet criteria defined by **[V2 7007] Food and Production Area Microorganism Levels**, **[V2 7111] Food Safety**, and **[V2 7112] Food Production Facility**. Techniques vary based on the item's perishability and ingredients.
  - Thermostabilization
  - Irradiation
  - Freeze drying (dehydration)
- Human spaceflight programs that do not follow NASA's food selection and testing protocols should prepare to test for a wider array of bacteria, (such as *listeria*), as well as consider downstream effects such as strain on waste management systems.

See OCHMO-TB-013 Food and Nutrition Brief for info on preparation, transport processes, and Food System Design

Food Preservation and Disposal

- Food areas of the spacecraft must meet the criteria defined by **[V2 7010] Food Contamination Control** and **[V2 7015] Food System Cleaning and Sanitizing**
- After eating, packages should be disposed of and have no food remnants to limit bacterial growth.
  - On the ISS, trash is packed into resupply vehicles which either return to Earth or burn upon atmospheric entry (**[V2 7064] Trash Accommodation**)

Spoilage Microorganisms	Pathogenic Microorganisms
Yeasts, molds, fungi, or bacteria that grow on food after a period of being left out. They cause food to smell, taste, and look bad, and in some cases can produce harmful toxins.	Microorganisms that causes disease or illness to their host. Often due to improper cooking or handling and difficult to detect from sight, smell, or taste.

Reference Data

Example pathogens found in food, water, and air on Earth

Please note that while these microbes, fungi, and viruses may be present, their survivability is dependent upon environment, food source, etc. Human exposure limits to these pathogens are variable.

Pathogen	Location Found	Incubation (Infection to symptoms)	Symptoms	Example Treatments
E. coli	Food: leafy greens, sprouts, raw milk, raw beef, poultry; water	1 - 10 days	Abdominal cramps, diarrhea, fatigue	Hydration, antibiotics
Salmonella	Food: vegetables, meat, fruits, nuts, eggs, sprouts	6 hours - 6 days	Fever, abdominal cramps, nausea, vomiting, diarrhea	Hydration, no treatment, or antibiotics
Listeria	Food: raw milk products, fruits, vegetables, sprouts, ready-to-eat meats; water and soil	3 hours - 10 days	Fever, muscle aches, nausea, vomiting, diarrhea	Hydration, antibiotics
Cyclospora	Food: raspberries, basil, cilantro, snow peas, mesclun lettuce	2 – 14 days	Abdominal cramps, diarrhea, fatigue	Trimethoprim-sulfamethoxazole (TMP-SMX) antibiotics
Cronobacter sakazakii	Food: low-moisture, dry foods such as powders, starches, and teas	6 – 8 hours	Dependent on age and health. In adults: diarrhea and UTIs	No treatment or antibiotics
Staphylococcus	Skin and nose, becomes problematic if inside the body (bloodstream, lungs, heart)	1-6 hours to 4-10 days	Highly variable: bacteremia (bloodstream infection); endocarditis (heart infection); boils, rashes (skin infection); vomiting, diarrhea (food poisoning)	Antibiotics
Norovirus	Food and drink contaminated by infected individuals	12-48 hours	Diarrhea, vomiting, nausea, stomach pain	No treatment available
Hepatitis A	Food: water, shellfish, raw vegetables and fruit (berries), salads	14 - 28 days	Fever, diarrhea, nausea, dark-colored urine, jaundice	No treatment available; treat symptoms
Aspergillus	Spores are found in soil, water, and air	1-56 days	Vary based on type of aspergillosis. Include asthma symptoms, coughing up blood, chest pain, fatigue	Antifungal medications

Skin

- Microbes live on healthy human skin, including bacteria such *Staphylococcus, Corynebacterium*, and *Propionibacterium* genera, as well as a variety of fungi, viruses, and mites.
- However, skin can also carry opportunistic pathogens that cause a wide range of diseases; these pathogens can also develop antibiotic resistance.
- Instances of skin and subcutaneous infections are not uncommon during spaceflight missions, as demonstrated during STS-1 through STS-89 where they represented 8.1% of all medical events. (Risin, 2009; https://humanresearchroadmap.nasa.gov/Evidence/reports/EvidenceBook.pdf)

Reference Data

Waste

- Pathogens from body waste can utilize several routes of infection to cause a variety of diseases
- Collection, containment, and disposal of body waste to prevent cross-contamination must be considered in waste management system design (**[V2 7020] Body Waste Management Capability** and **[V2 7025] Body Waste Containment**)
- In the event of mortality related to spaceflight, human remains present additional opportunity for contamination:
  - Current plans for containment of remains depends on mission duration and objective, but must prevent odor leakage and environmental contamination, and consider planetary protection

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

NASA-STD-3001 Volume 2 Revision D

Reference the OCHMO-TB-041 Body Waste Management Technical Brief for additional information on storage systems, and OCHMO-TB-012 Mortality Related to Human Spaceflight Technical Brief for information on human remains.

Planetary Protection

- Planetary protection is an effort agreed upon by UN member states to control both forward contamination of other worlds by terrestrial microorganisms, and backwards contamination of Earth by extraterrestrial life or bioactive molecules
- For more detail, consult the guidelines outlined by the Office of Planetary Protection, specifically Technical Standard NASA-STD-8719.27
- This pertains to containment of biological experiments sent to space, which is regulated by the government of the company or agency flying the experiment. NASA-flown experiments must comply with criteria defined by **[V2 6060] Biological Payloads**.

Apollo 11 crew quarantined after mission to the moon due to concerns of planetary protection. Crew are not quarantined upon return from the ISS.
NASA, photo ID: S69-21365

Risk of Adverse Health Effects Due to Host-Microorganism Interactions:
"Given that evidence collected during space flight indicates alterations in microbial virulence and astronaut immune function, there is a possibility that infectious disease will have increased prevalence and/or will be more severe during spaceflight missions."

Reference Data

One of several BioRisk experiments investigated physical and genetic changes in bacteria and fungi on surfaces of the ISS. Researchers found that microorganisms retain their reproductive ability and **exhibit increased virulence and resistance to antibiotics.**

Virulence

- Conditions of the space environment can modify:
  - Ability to cause disease or illness (virulence)
  - Microbial characteristics (pathogenicity)
  - Gene expression
  - Biofilm formation
- A study of *Salmonella typhimurium* aboard the ISS showed that the bacteria more lethal to mice, had enhanced biofilm production, and differentially expressed 167 genes (Wilson 2008).
- Other studies saw differences in cell aggregation, antifungal and stress resistance, hyphal formation, and biomass thickness (Kim 2013, Crabbe 2013, Tixador 1985).
- Astronauts who worked on the ISS for 23 days showed an increase in their neutrophil numbers, which may be a compensatory mechanism to offset the decreased phagocytic capacity of cells (Ott 2004).

ISS surface biofilm virulence experiment samples
Source: https://news.mit.edu/2023/preventing-biofilms-space-0907

Pre-flight Testing

- In current NASA practices, sample collection occurs 10-15 days before launch:
  - Food: sampled after preparation and tested for a specific set of illness-causing bacteria
  - Surfaces: swab 25cm^2 area of a surface, re-suspend and plate
  - Water: collect and plate 100mL of water
  - Air: use microbial air aggregating device to plate airborne microorganisms
  - Samples are grown on trypticase soy agar (bacteria) or Sabouraud dextrose agar (fungi) and are identified with a combination of sequencing and microscopy techniques. Based on sampled volume, the CFU per area/volume is determined, and must be within the limits:

Pre-Flight Testing		
Sample Type	**Acceptability Limit**	
	Bacteria	**Fungi**
Air	300 CFU/100 cm^3	50 CFU/100 cm^3
Surface	500 CFU/100 cm^2	10 CFU/100 cm^2
Water	50 CFU/mL No detectable coliforms	

Acceptability limits of Pre-Flight limits defined in the ISS Medical Operations Requirements Document, NASA.

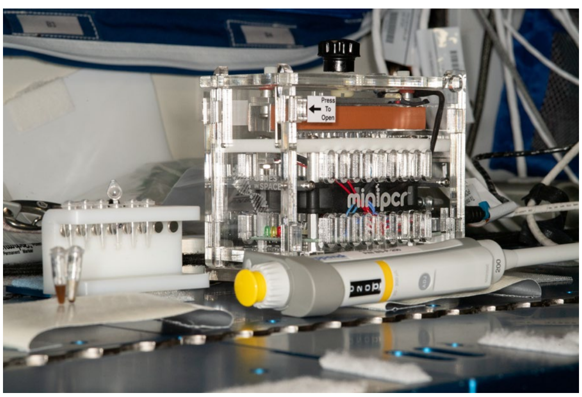
- Crew should be illness-free, an uncompromised immune system, and have the proper vaccinations (influenza, tetanus, diphtheria, acellular pertussis, MMR (mumps, measles, rubella), Hepatitis A and B) at the time of launch (**[V1 3002] Pre-Mission Preventive Health Care**).
- Crew are quarantined before launch for two weeks to mitigate contamination.

Reference OCHMO-TB-034 Crew Selection and Recertification Technical Brief and the OCHMO-TB-006 Health Stabilization Program (HSP) Technical Brief for additional information.

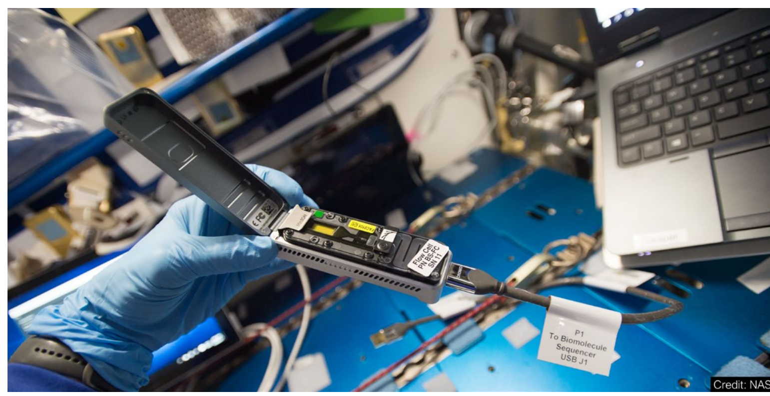
Reference Data

In-flight Testing

- Currently, the microbiology of the ISS is routinely monitored via various collection methods, growth on different media types, and testing on Earth.
- Culture-independent methods, where bacteria do not need to be grown prior to sequencing analysis, are being developed to save precious time and resources.
    - Countermeasures to microbial risks identified by the Human Systems Risk Board (HSRB) include in situ testing: In-flight microbial monitoring for research and crew health during Gateway, Lunar, and Mars missions.
- Oxford Nanopore Technologies' MinION™ sequencer and miniPCR bio's miniPCR™ thermal cycler have been investigated on the ISS to immediately identify type (though not necessarily quantity) of specific bacteria.



miniPCR™ thermal cycler aboard the ISS.
miniPCR Bio



Nanopore MinION sequencer aboard the ISS.
Oxford Nanopore Technologies

In-Flight Testing		
Sample Type	**Acceptability Limit**	
	Bacteria	**Fungi**
Air	1000 CFU/m^3	100 CFU/m^3
Surface	10,000 CFU/100 cm^2	100 CFU/100 cm^2
Water	50 CFU/mL No detectable coliforms	

Acceptability limits of Pre-Flight limits defined in the ISS Medical Operations Requirements Document, NASA.

- NASA currently conducts in-flight sampling aboard the ISS. However, there is debate over whether routine testing or simply as-needed diagnostic testing in response to illness is the best practice. Crew and systems health must be weighed against efficient use of time and resources.
- Spacecraft and crew must be capable of providing adequate medical care if microbial testing indicates a health risk to crew (**[V1 3004] In-Mission Medical Care**).

Application

Vehicle design must aim to mitigate microbial contamination and disease-causing conditions, especially if accommodating bioregenerative food systems or other novel biological processes.

See OCHMO-TB-025 Cabin Architecture Technical Brief for additional information.

Design Recommendations to Limit Exposure

Surface Materials

In addition to integrity and weight, materials should be chosen according to their cleanability and antimicrobial properties to minimize biocontamination. Ideal metals are **stainless steel alloys, titanium, platinum, and silver alloys**. Avoid fabrics, glass, paper, wood, uncoated aluminum, copper, and only use plastics and rubbers when necessary.

Antimicrobial Surfaces

- FDA regulatory approval for **food-contact coatings** is described in 21 C.F.R. 177.168
- **Anatase titanium**. The mechanism relies on the formation of free radicals from the breakdown of water and oxygen following illumination with UV light in the range of 254–395 nm
- **Polylactide** (PLA). Even more effective when titanium dioxide is incorporated during casting and illuminated with UV-A. Stable in repeated detergent and sodium hypochlorite rinses

Touch panels installed for the ISS Boeing Antimicrobial Coating investigation.
Space Station 101: Microbiology, NASA

Cabin Design for Function and Ergonomics

Surfaces, tools, and habitat should be designed to be easily cleanable (**[V2 7082] Surface Material Cleaning**).

Suggestions for Surface Materials and Design

Have a smooth and rounded design
Contain no crack or crevice of any type
Made of nonporous and nonabsorbent material
Not react to any food product
Resist corrosion, contamination, and wear
Require no maintenance
Contain no toxins
Be easily cleanable

Past issues with biological contamination and formation of biofilms have been due to small crevices and moist environments. Consider connections in machinery and seal off openings to prevent leakages.

For more information, follow Sanitary and Hygienic Design for Food Equipment Manufacturers. USDA (www.usda.ams.gov) or NSF (www.nsf.org/food-beverage/commercial-food-equipment).

Application

Filtration Systems

- The Potable Water Recovery System should:
  - Recover and dispense potable water for drinking, rehydration, medical uses, and washing
  - Process water so that it has a palatable taste and is chemically and microbiologically safe for human use
  - Monitor water quality and notify the crew as defined limits are approached (**[V2 6051] Water Contamination Control** and **[V2 6046] Water Quality Monitoring and Alerting**)
- The Air Filtration System should:
  - Provide cabin air circulation and thermal control
  - Have trace contaminant control, CO_2 scrubbing, and atmospheric monitoring
  - Catch and remove airborne particles (typically 99.97% of airborne particles 0.3 µm in diameter)
  - Have a flowrate that is appropriate for cabin size & function

Charcoal filters integrated into HEPA filters capture chemicals including harmful siloxanes like dimethylsilanediol (DMSD) produced from off-gassing of products. Filtration specificity must be considered. Testing, design, and implementation of charcoal-HEPA filters for the ISS can be found in Breman, et. al 2019.

NASA astronauts on the ISS clean surfaces and crevices of the habitat every Saturday for around 3 hours.

NASA astronauts wiping panels and vacuuming the ISS.
(top) NASA photo id: iss056e099195
(bottom) NASA photo id: iss022e014698

Housekeeping and Hygiene

Housekeeping practices and associated operations should support mitigation of microbial growth and cross-contamination (**[V2 6063] Contamination Cleanup**).

Tools and Products

- Personal hygiene kits (comb, toothbrush, toothpaste, floss, soap, lip balm, deodorant, etc.)
- Vacuum cleaner
- Disinfectant, wipes, towels
- Hand-held UVC lamps or fixed lamps

Ultraviolet Germicidal Irradiation (UVGI) can be used to disinfect air or surfaces. Essentially, the DNA of the microbe is disrupted by the UV radiation, leaving them unable to grow or reproduce. Ideal wavelengths are in the range of 200 - 300 nm. Longer wavelength UV rays become harmful to human eyes and skin. **[V2 6117] Artificial Light Exposure Limits** should be consulted for appropriate threshold limit values.

Application

See the NASA OCHMO-TB-015 Spaceflight Toxicology Technical Brief for additional information.

Disinfectant Products

- Products should not degrade habitat materials or be toxic to crew

Biocides and Antimicrobial mitigation agents - Considerations for media, toxicity, and off-gassing

Biocide	Mode of Action	Pros	Cons
Iodine	Oxidizes proteins, nucleotides, and fatty acids, killing the cell	Effective against bacteria, fungi, yeasts, viruses, spores, and protozoan parasites	Light-sensitive; excess iodine ingestion is associated with thyroid disorders
Chlorine	Disturbs the production of ATP, a compound crucial to cell survival	Cheap, widely used, eliminates tastes and odors from water	Depending on concentration, inhalation can cause beathing difficulty or severe lung conditions
Silver Ions	Prevents further growth of cells by inhibiting parts of DNA replication	Silver compounds can be included in water filtration, used to coat surfaces	Nanosilver and silver colloid are potentially toxic to humans and can accumulate in tissues via inhalation
Soap & water	Soap molecules lift germs from the surface	Highly effective for bacteria	Difficult to use in space

Personal Hygiene

- As stated in **[V2 7016] Personal Hygiene Capability**, system should have:
  - Body cleansing capability
  - Oral hygiene
  - Personal grooming
  - Sufficient quantities of clean, durable clothing

Medical Treatment Capability

- Antibiotics
- Antiseptics
- Antifungal medications
- Antiviral medications
- Other supportive care, intended to minimize consequence of infection and prevent the development of sepsis.

<u>Agriculture</u>

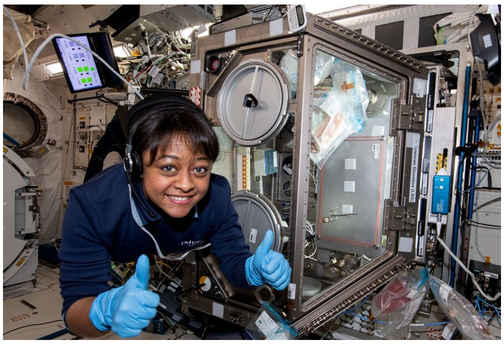
- Growing crops allows for consumption of fresh food and in situ resource utilization for long-term space travel.
- Produce must be properly cleaned and disinfected before consumption (i.e. chlorine dips or washing with soap and water).
- Studies conducted by NASA's Human Research Program are ongoing to better understand growth of plants in space.

Fungal contamination on a plant grown in the Veggie plant habitat.
NASA

Application

Biological Systems & Special Modules

- Refer to the CDC's Biosafety in Microbiological & Biomedical Laboratories (BMBL) for standard practices and personal protective equipment (PPE).
- Flying high-risk pathogens for experimental purposes has precedent but must get biosafety approval from the space agency or company who is flying the experiment. Payloads flown through NASA shall meet criteria and follow procedures as stated by **[V2 6060] Biological Payloads**.



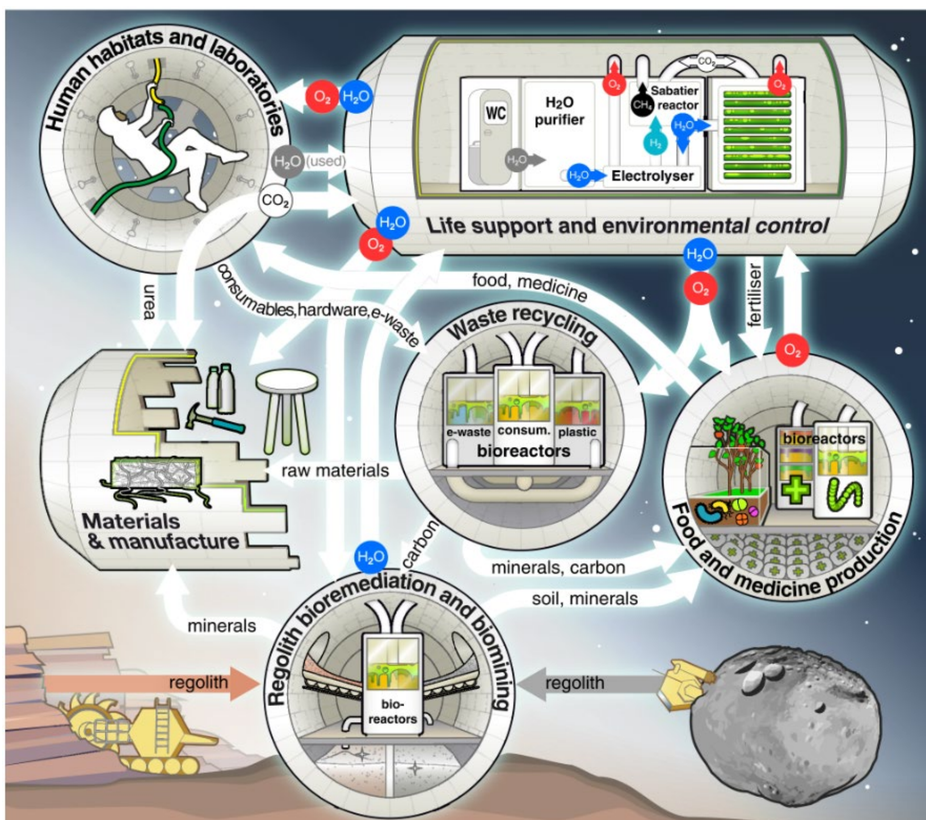
Astronaut conducting a biological experiment with proper PPE.
Axiom Space, Ax-2 Crew

[V2 6061] Environment Cross-Contamination The system shall provide controls to prevent or 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.

From: NASA-STD-3001 Volume 2 Revision D

Long-distance & Long-duration Missions

- Use of microbes to close the loop of a sustainable space ecosystem must avoid cross-contamination and consider the health of the crew
- Long-distance missions have hazards including deep space radiation which could heighten the risk of infectious disease
- Long-term growth of microbes in decreased gravity could alter microbial mutational rates and associated heritable characteristics
- Quiescent periods, where microbes do not replicate but retain capability of renewed division, must be considered



Microbial biotechnology-based life-support system explained in Santomartino et. al 2023.

Back-Up

Major Changes Between Revisions

Original → Rev A

- Updated Executive Summary for considerations regarding immune status.

View the current versions of NASA-STD-3001 Volume 1 & Volume 2 on the OCHMO Standards website

Referenced Technical Requirements

NASA-STD-3001 Volume 1 Revision C

[V1 3002] Pre-Mission Preventive Health Care Pre-mission preventive strategies shall be used to reduce in-mission and long-term health medical risks, including, but not limited to: (see NASA-STD-3001, Volume 1 Rev C for full technical requirement).

[V1 3004] In-Mission Medical Care All programs shall provide training, in-mission medical capabilities, and resources to diagnose and treat potential medical conditions based on epidemiological evidence-based PRA, individual crewmember needs, clinical practice guidelines, flight surgeon expertise, historical review, mission parameters, and vehicle-derived limitations. These analyses consider the needs and limitations of each specific vehicle and design reference mission (DRM) with particular attention to parameters such as: (see NASA-STD-3001, Volume 1 Rev C for full technical requirement).

NASA-STD-3001 Volume 2 Revision D

[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 6046] Water Quality Monitoring and Alerting The system shall provide the capability to monitor water quality and notify the crew locally and remotely when parameters are approaching defined limits.

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

[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 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.

[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 7007] Food and Production Area Microorganism Levels Microorganism levels in the food and production area shall not exceed those specified in Table 7.1-3--Food Microorganism Levels.
[V2 7008] Food Preparation The system shall provide the capability for preparation, consumption, and stowage of food.

All referenced tables and figures are available in NASA-STD-3001 Volume 2 Revision D.

View the current versions of NASA-STD-3001 Volume 1 & Volume 2 on the OCHMO Standards website

Referenced Technical Requirements

NASA-STD-3001 Volume 2 Revision D

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

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

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

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

[V2 7111] Food Safety The program shall maintain flight food safety throughout product life cycle.

[V2 7112] Food Production Facility The facility where food is prepared, processed, packaged, stowed, and stored shall comply with applicable laws and regulations, or FDA equivalent, as well as industry Good Manufacturing Practice standards.

[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 body waste management system.

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

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

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

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

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

[V2 11125] Suit Materials Compatibility Pharmaceuticals, topical treatments and cleaning materials shall be compatible with suit materials (internally and externally).

[V2 11126] Suit Materials Cleanability The suit materials (internally and externally) shall be compatible with the expected cleaning materials and methods.

All referenced tables and figures are available in NASA-STD-3001 Volume 2 Revision D.

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