Life Support Systems
Microbial Challenges

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Agenda

• Environmental Control and Life Support Systems (ECLSS) What is it?

• A Look Inside the International Space Station (ISS)

• The Complexity of a Water Recycling System

• ISS Microbiology Acceptability Limits

• Overview of Current Microbial Challenges

• In a Perfect World What we Would Like to Have

• The Future
Environmental Control and Life Support Systems (ECLSS)

- Control Atmosphere Pressure
- Condition Atmosphere
- Respond to Emergency Conditions
- Control Internal CO2 & Contaminants
- Provide Water
Note: These values are based on an average metabolic rate of 136.7 W/person (11,200 BTU/person/day) and a respiration quotient of 0.87. The values will be higher when activity levels are greater and for larger than average people. The respiration quotient is the molar ratio of \( \text{CO}_2 \) generated to \( \text{O}_2 \) consumed.

**Human Needs and Effluents Mass Balance (per person per day)**

- **Oxygen** = 0.84 kg (1.84 lb)
- **Food Solids** = 0.62 kg (1.36 lb)
- **Water in Food** = 1.15 kg (2.54 lb)
- **Food Prep Water** = 0.76 kg (1.67 lb)
- **Drink** = 1.62 kg (3.56 lb)
- **Metabolized Water** = 0.35 kg (0.76 lb)
- **Hand/Face Wash Water** = 4.09 kg (9.00 lb)
- **Shower Water** = 2.73 kg (6.00 lb)
- **Urinal Flush** = 0.49 kg (1.09 lb)
- **Clothes Wash Water** = 12.50 kg (27.50 lb)
- **Dish Wash Water** = 5.45 kg (12.00 lb)

**Total Needs** = 30.60 kg (67.32 lb)

- **Carbon Dioxide** = 1.00 kg (2.20 lb)
- **Respiration & Perspiration Water** = 2.28 kg (5.02 lb)
- **Food Preparation, Latent Water** = 0.036 kg (0.08 lb)
- **Urine** = 1.50 kg (3.31 lb)
- **Urine Flush Water** = 0.50 kg (1.09 lb)
- **Feces Water** = 0.091 kg (0.20 lb)
- **Sweat Solids** = 0.018 kg (0.04 lb)
- **Urine Solids** = 0.059 kg (0.13 lb)
- **Feces Solids** = 0.032 kg (0.07 lb)
- **Hygiene Water** = 12.58 kg (27.68 lb)

**Total Effluents** = 30.60 kg (67.32 lb)
A Look Inside ISS
Living in Space
Filling up a bag of water in the Zvezda, SM
Water Processor Assembly

- **Ion Exchange Bed** (removes reactor by-products)
- **Reactor** (oxidizes organics)
- **Preheater** (heats water to 275°F)
- **Regen. HX** (recovers heat)
- **Gas/Liquid Separator** (removes oxygen)
- **Particulate Filter** (removes particulates)
- **Multifiltration Beds** (remove dissolved contaminants)
- **Mostly Liquid Separator** (removes air)
- **Filter Pump**
- **Wastewater Tank**
- **Product Water Tank**
- **Delivery Pump**
- **Accumulator**

**Nodes and Connections**:
- **O2 from Node 3 to Node 3 cabin**
- **From Node 3 wastewater bus to Node 3 potable water bus**
- **Heat Exchanger** to/from Node 3 MTL
- **Reject Line** (allows reprocessing)
- **Microbial Check Valve** (provides isolation)
- **CC Reactor Health Sensor** (verifies reactor is operating w/in limits)

**Related Components**:
- **Water Processor**
- **Assembly**
ECLSS Microbial Challenges

- Wetted Materials in space life support systems include:
  - Titanium
  - 316L Stainless Steel
  - Teflon
  - Viton O-rings
  - Nickel-Brazed Stainless Steel
## ECLSS Microbial Challenges

### ISS Microbial Acceptability Limits (U.S.)

<table>
<thead>
<tr>
<th></th>
<th>Bacteria</th>
<th>Fungi</th>
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</thead>
<tbody>
<tr>
<td><strong>Surfaces</strong></td>
<td>10,000 CFU/100 cm²</td>
<td>100 CFU/100 cm²</td>
</tr>
<tr>
<td><strong>Water</strong></td>
<td>100 CFU/ 100 ml (no detectable coliforms)</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Air</strong></td>
<td>≤ 1,000 CFU/m³</td>
<td>100 CFU/ m³</td>
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</table>

CFU/cm² = colony forming units per square centimeter; CFU/cm³ = colony forming units per cubic meter; CFU/ml = colony forming units per milliliter
ADVERSE EFFECTS OF MICROBIAL CONTAMINATION

Short-term Effects (days to weeks)

Air/Surfaces:
- Release of volatiles (e.g., odors)
- Allergies (e.g., skin, respiratory)
- Infectious diseases (e.g., Legionnaire's)

Water:
- Objectionable taste/odor
- Gastrointestinal distress

From Victoria Castro, ICES 2006, JSC

Long-term Effects (weeks to years)

Air/Surfaces (same as short-term plus):
- Release of toxins (e.g., mycotoxins)
- Sick building syndrome
- Environmental contamination
- Biodegradation of materials
- Systems performance

Water (same as short-term plus):
- System failure
- Clogging, corrosion, pitting, antimicrobial resistance/regrowth potential (biofilm)
ECLS Microbial Challenges

- **Urine/Pretreated Urine**
  - Hardware Performance Issues
    - Control of biofilm on wetted surfaces
    - Control of fungal growth in pretreated urine

- **Water (potable/wastewater)**
  - Health and Hardware Performance/Life Issues
    - Control of biofilm on wetted surfaces
      - Conditions of flight equipment unknown
    - Control of microorganisms in potable water
      - Re-growth potential/resistance to antimicrobials/MIC
    - Control microorganisms in humidity condensate
ECLS Microbial Challenges

- **Coolant**
  - Health and Hardware Performance/Life Issues
    - Control of microorganisms in the fluid
    - Control of biofilm on wetted surfaces
    - Microbiologically Influenced Corrosion (MIC)

- **Surfaces**
  - Health and Hardware Performance/Life Issues
    - Fungi, bacteria

- **Air**
  - Health and Hardware Performance/Life Issues
    - Fungi, bacteria
ECLSS Microbial Challenges (Design and Test)

- Flow rates: low, intermittent or no flow
- Dead-legs
- Potential long term storage of water in Teflon bags
- Limitations with the use of antimicrobials
- Gravity/microgravity effects
- Wastewater in narrow tubes
ECLSS Microbial Challenges (Design and Test)

- Holding time (between sample and analysis)
- Limited monitoring technology available
- Data interpretation
- Acceptable levels of microorganisms/biofilm
- Need for long term ground testing
- Replicate applicable flight conditions to ground tests
<table>
<thead>
<tr>
<th>Species</th>
<th>Fleet Leader (Ground Test)</th>
<th>ISS LTL (Flight Sample)</th>
<th>ISS MTL (Flight Sample)</th>
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<tbody>
<tr>
<td>Acidovorax avenae</td>
<td>X</td>
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<tr>
<td>Acidovorax delafieldii</td>
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<td>Acidovorax facilis</td>
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<td>Acidovorax konjaci</td>
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<td>Acidovorax temperans</td>
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<tr>
<td>Acinetobacter lwofii/genospecies 9</td>
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<tr>
<td>Brevibacterium casei</td>
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<tr>
<td>Brevundimonas vesicularis</td>
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<td>Burkholderia glumae</td>
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<td>Comamonas acidovorans</td>
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<td>Flavobacterium resinovorum</td>
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<td>Janthinobacterium lividum</td>
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<tr>
<td>Oligella species</td>
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<tr>
<td>Ralstonia eutropha (very similar genetically to R. paucula)</td>
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<tr>
<td>Ralstonia paucula</td>
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<tr>
<td>Ralstonia pickettii</td>
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<tr>
<td>Sphingobacterium spiritovorum</td>
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<tr>
<td>Sphingomonas paucimobilis</td>
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<td>Stenotrophomonas maltophilia</td>
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<tr>
<td>Unidentified non-fermenting Gram Negative Rod (GNR)</td>
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<tr>
<td>Variovorax paradoxus</td>
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Challenges with monitoring ECLS systems in-flight include:

• Microbial count (quantification)
  – Viable vs non-viable
  – How will it compare with culture methods?

• Real-time identification
  – Bacteria, Fungi, Viruses

• Flexible
  – Integrated to systems (in-line)
  – Hand-held (for clinical applications)

• Robustness
  – Will the hardware survive qual/acceptance testing?
If gene-base technology will be used what challenges, like damage to genetic material due to radiation, will need to be addressed?

- Expendables (how much waste will be generated)
- Consumables (reusable is preferred)
- Low power consumption
- Equipment size
- Non-hazardous reagents
- Non-generation of hazardous waste
ECLSS Microbial Challenges

- Calibration (positive/negative controls?)
- Cleaning/disinfection of the sample collection areas
  - How to avoid cross contamination?
- What chemicals/conditions (temp, humidity, etc) could cause a problem (void the reaction)?
- Maintenance/repair (ORU’s?)
- Construction materials
  - Are the materials acceptable in a close environment?
ECLSS Microbial Challenges

- Sample size
- Detection limit (currently <300 CFU/100 mL)
- Microgravity sensitivity
- Sensitivity to particles/precipitates in the fluid
- A system that can be upgraded as needed is preferable (as “target” organisms are identified)
- Will the crew be able to “read” the results on-orbit; can the results be sent to the ground?
- Sample archival for later analyses