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

NASA/ M. Roman
Environmental Control and Life Support Systems (ECLSS)

- Control Atmosphere Pressure
- Condition Atmosphere
- Respond to Emergency Conditions
- Control Internal CO2 & Contaminants
- Provide Water
Human Needs and Effluents Mass Balance (per person per day)

<table>
<thead>
<tr>
<th>Needs</th>
<th>Effluents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen = 0.84 kg (1.84 lb)</td>
<td>Carbon Dioxide = 1.00 kg (2.20 lb)</td>
</tr>
<tr>
<td>Food Solids = 0.62 kg (1.36 lb)</td>
<td>Respiration &amp; Perspiration Water = 2.28 kg (5.02 lb)</td>
</tr>
<tr>
<td>Water in Food = 1.15 kg (2.54 lb)</td>
<td>Food Preparation, Latent Water = 0.036 kg (0.08 lb)</td>
</tr>
<tr>
<td>Food Prep Water = 0.76 kg (1.67 lb)</td>
<td>Urine = 1.50 kg (3.31 lb)</td>
</tr>
<tr>
<td>Drink = 1.62 kg (3.56 lb)</td>
<td>Urine Flush Water = 0.50 kg (1.09 lb)</td>
</tr>
<tr>
<td>Metabolized Water = 0.35 kg (0.76 lb)</td>
<td>Sweat Solids = 0.018 kg (0.04 lb)</td>
</tr>
<tr>
<td>Hand/Face Wash Water = 4.09 kg (9.00 lb)</td>
<td>Urine Solids = 0.059 kg (0.13 lb)</td>
</tr>
<tr>
<td>Shower Water = 2.73 kg (6.00 lb)</td>
<td>Feces Water = 0.091 kg (0.20 lb)</td>
</tr>
<tr>
<td>Urinal Flush = 0.49 kg (1.09 lb)</td>
<td>Feces Solids = 0.032 kg (0.07 lb)</td>
</tr>
<tr>
<td>Clothes Wash Water = 12.50 kg (27.50 lb)</td>
<td>Hygiene Water = 12.58 kg (27.68 lb)</td>
</tr>
<tr>
<td>Dish Wash Water = 5.45 kg (12.00 lb)</td>
<td>Liquid = 11.90 kg (26.17 lb)</td>
</tr>
<tr>
<td></td>
<td>Latent = 0.60 kg (1.33 lb)</td>
</tr>
<tr>
<td>Total = 30.60 kg (67.32 lb)</td>
<td>Total = 30.60 kg (67.32 lb)</td>
</tr>
</tbody>
</table>

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 CO$_2$ generated to O$_2$ consumed.
Space Station Regenerative ECLSS
Flow Diagram (Current Baseline)
International Space Station ECLSS
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 275F)
- 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
- 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)
- C Cabin Reactor Health Sensor (verifies reactor is operating w/n limits)
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>
</tr>
</thead>
<tbody>
<tr>
<td>Surfaces</td>
<td>10,000 CFU/100 cm²</td>
<td>100 CFU/100 cm²</td>
</tr>
<tr>
<td>Water</td>
<td>100 CFU/100 ml (no detectable coliforms)</td>
<td>N/A</td>
</tr>
<tr>
<td>Air</td>
<td>≤ 1,000 CFU/m³</td>
<td>100 CFU/ m³</td>
</tr>
</tbody>
</table>

CFU/cm² = colony forming units per square centimeter; CFU/m³ = 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>Bacteria</th>
<th>Fleet Leader (Ground Test)</th>
<th>ISS LTL (Flight Sample)</th>
<th>ISS MTL (Flight Sample)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Acidovorax avenae</em></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Acidovorax delafieldii</em></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td><em>Acidovorax facilis</em></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Acidovorax konjaci</em></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Acidovorax temperans</em></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Acinetobacter lwaffii/genospecies 9</em></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><em>Brevibacterium casei</em></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><em>Brevundimonas vesicularis</em></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><em>Burkholderia glumae</em></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Comamonas acidovorans</em></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td><em>Flavobacterium resinovorum</em></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><em>Janthinobacterium lividum</em></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Oligella species</em></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><em>Ralstonia eutropha</em> (very similar genetically to R. paucula)*</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><em>Ralstonia paucula</em></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><em>Ralstonia pickettii</em></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><em>Sphingobacterium spiritovorum</em></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><em>Sphingomonas paucimobilis</em></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><em>Stenotrophomonas maltophilia</em></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><em>Unidentified non-fermenting Gram Negative Rod (GNR)</em></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><em>Variovorax paradoxus</em></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
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?
ECLSS Microbial Challenges

- 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
The End?