Life Support Systems
Microbial Challenges

August 24, 2009

Monsi C. Roman
NASA/ Marshall Space Flight Center
ECLSS Chief Microbiologist
(256)544-4071
Protect the environment, save lives. Implement a system that

- 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 CO\(_2\) generated to 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)

### Effluents

- **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)

### Total

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

**Effluents** = 30.60 kg (67.32 lb)
Space Station Regenerative ECLSS
Flow Diagram (Current Baseline)
A Look Inside ISS
Living in Space
Filling up a bag of water in the Zvezda, SM
ISS Water Processor Diagram

- Wastewater Tank
- Particulate Filter (removes particulates)
- Multifiltration Beds (remove dissolved contaminants)
- 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)
- Mostly Liquid Separator (removes air)
- Filter
- Microbial Check Valve (provides isolation)
- Product Water Tank
- Delivery Pump
- Accumulator
- O2 from Node 3
- Reactor Health Sensor
- Heat Exchanger (allows reprocessing)
- MTL Reject Line
- To Node 3 cabin
- From Node 3 wastewater bus
- From Node 3 potable water bus
- To Node 3 cabin

NASA/ M. Roman 21
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)

CC Reactor Health Sensor (verifies reactor is operating w/n limits)

CC
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><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>
</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

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)

From Victoria Castro, ICES 2006, JSC
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></th>
<th>Fleet Leader (Ground Test)</th>
<th>ISS LTL (Flight Sample)</th>
<th>ISS MTL (Flight Sample)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidovorax avenae</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acidovorax delafeldii</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Acidovorax facilis</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Acidovorax konjacii</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Acidovorax temperans</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Acidovorax delafieldii</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acidovorax facilis</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acidovorax konjacii</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acidovorax temperans</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Acinetobacter lwofii/genospecies 9</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Brevibacterium casei</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Brevundimonas vesicularis</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Burkholderia glumae</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comamonas acidovorans</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Flavobacterium resinovorum</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Janthinobacterium lividum</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oligella species</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Ralstonia eutropha (very similar genetically to R. paucula)</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Ralstonia paucula</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Ralstonia pickettii</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sphingobacterium spiritovorum</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Sphingomonas paucimobilis</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Stenotrophomonas maltophilia</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Unidentified non-fermenting Gram Negative Rod (GNR)</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Variovorax paradoxus</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
ECLSS Microbial Challenges

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
The End?