Life Support Systems
Microbial Challenges

August 24, 2009

Monsi C. Roman
NASA/ Marshall Space Flight Center
ECLSS Chief Microbiologist
(256)544-4071
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 CO$_2$ generated to O$_2$ consumed.
International Space Station ECLSS

- Waste Management (Waste Mgt.)
- Urine Recovery
- Processed Urine
- Potable Water Processing
- Crew System
- Hand Wash/Shaving
- Potable Water Dispenser
- Wastewater
- Temp. & Humidity Control
- Cabin Air
- Cabin Return
- Return Air
- CO₂ Removal
- CO₂ Reduction
- Trace Contaminant Control Subassembly
- Fire Detection & Suppression
- Oxygen Generation
- H₂
- Oxygen
- Nitrogen
- Product Water
- Water
Living in Space
Filling up a bag of water in the Zvezda, SM
ISS Water Processor Diagram

- Wastewater Tank
  - to Node 3 cabin
  - from Node 3 wastewater bus

- Particulate Filter
  - removes particulates

- Ion Exchange Bed
  - removes reactor by-products

- Reactor
  - oxidizes organics
  - from Node 3

- Preheater
  - heats water to 275°F

- Regen. HX
  - recovers heat

- Gas/Liquid Separator
  - removes oxygen

- Multifiltration Beds
  - remove dissolved contaminants

- Mostly Liquid Separator
  - removes air

- Filter
  - provides isolation

- Microbial Check Valve
  - allows reprocessing

- Product Water Tank
  - provides isolation

- Reactor Health Sensor
  - verifies reactor is operating within limits

- Heat Exchanger
to/from Node 3 MTL

- Delivery Pump
  - to Node 3 potable water bus

- Accumulator

- O2 from Node 3
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>Category</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></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 delafieldii</td>
<td>X</td>
<td>X</td>
<td>X</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>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acinetobacter lwofii/genospecies 9</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brevibacterium casei</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brevundimonas vesicularis</td>
<td>X</td>
<td></td>
<td></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>X</td>
<td></td>
<td></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>X</td>
<td></td>
<td></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>X</td>
<td></td>
</tr>
<tr>
<td>Sphingomonas paucimobilis</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stenotrophomonas maltophilia</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unidentified non-fermenting Gram Negative Rod (GNR)</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Variovorax paradoxus</td>
<td>X</td>
<td></td>
<td></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