Space Life Support

- Overview
- Major Component Systems
- Open-loop Life Support
- Physico-Chemical
- Bioregenerative
- Extravehicular Activity
Life Support Block Diagram

Humans

O2
CO2
Water
Nutrients
Waste
Stores

U N I V E R S I T Y  O F  M A R Y L A N D

Space Life Support
Principles of Space Systems Design
Essentials of Life Support

- Air
  - Constituent control
    - $CO_2$ scrubbing
    - Humidity control
    - Particulate scrubbing
    - $O_2$, $N_2$ makeup
  - Temperature control
- Water
- Food
- Waste Management
ISS Life Support Schematic

ECLSS Mass Balance

Needs
- 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 = 30.60 kg (67.32 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)
- Hygiene Water = 12.58 kg (27.68 lb)
- Clothes Wash Water
  Liquid = 11.90 kg (26.17 lb)
  Latent = 0.60 kg (1.33 lb)
  Total = 30.60 kg (67.32 lb)

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 CO2 generated to O2 consumed.
<table>
<thead>
<tr>
<th>Consumable</th>
<th>Design Load (kg/person-day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>0.85</td>
</tr>
<tr>
<td>Water (drinking)</td>
<td>1.6</td>
</tr>
<tr>
<td>Water (in food)</td>
<td>1.15</td>
</tr>
<tr>
<td>Water (clothes and dishes)</td>
<td>17.9</td>
</tr>
<tr>
<td>Water (sanitary)</td>
<td>7.3</td>
</tr>
<tr>
<td>Water (food prep)</td>
<td>0.75</td>
</tr>
<tr>
<td>Food solids</td>
<td>0.62</td>
</tr>
</tbody>
</table>
## Effect of Regenerative Life Support

- Open loop life support: 100% resupply
- Waste water recycling: 45%
- $CO_2$ absorbent recycling: 30%
- $O_2$ regenerate from $CO_2$: 20%
- Food from wastes: 10%
- Eliminate leakage: 5%
Air Revitalization Processes

Cabin Atmospheric Pressure

• Past choices driven by minimum mass
  - Mercury/Gemini: 100% $O_2$ @ 3.5 psi
  - Apollo: 100% $O_2$ @ 5 psi
  - Skylab: 80% $O_2$/20% $N_2$ @ 5 psi
  - Shuttle/ISS: 21% $O_2$/79% $N_2$ @ 14.7 psi

• Issues of compatibility for docking vehicles, denitrogenation for EVA

• Current practice driven by avionics, concern for research protocols
Oxygen Makeup Systems

- **Gaseous \( O_2 \) storage (also \( N_2 \))**
  - Typical pressures 200 atm (mass optimized) to 500-700 atm (volume optimized)
  - 2 kg tank/kg \( O_2 \)

- **Liquid \( O_2 \) storage (also \( N_2 \))**
  - Requires 210 kJ/kg for vaporization (~2W/person)
  - Supercritical storage \( T=-118.8^\circ C, P=49.7 \) atm
  - 0.3-0.7 kg tank/kg \( O_2 \)

- **Solid perchlorates ("candles")**
  - \( LiClO_4 \rightarrow LiCl + 2O_2 + Q \) @ 700°C
  - 2.75 kg \( LiClO_4 \)/kg \( O_2 \) (Typically 12.5 kg with packaging)
Superoxides and Ozonides

- **O2 generation**
  - \( \text{KO}_2 + 2\text{H}_2\text{O} \rightarrow 4\text{KOH} + 3\text{O}_2 \)
  - \( \text{KO}_3 + 2\text{H}_2\text{O} \rightarrow 4\text{KOH} + 5\text{O}_2 \)

- **CO2 reduction**
  - \( 4\text{KOH} + 2\text{CO}_2 \rightarrow 2\text{K}_2\text{CO}_3 + 2\text{H}_2\text{O} \)
  - \( 2\text{K}_2\text{CO}_3 + 2\text{H}_2\text{O} + 2\text{CO}_2 \rightarrow 4\text{KHCO}_3 \)

- **KO2 removes 0.31 kg CO2/kg and generates 0.38 kg O2/kg**
# Nonregenerable O2 Production

<table>
<thead>
<tr>
<th>Material</th>
<th>kg(material)/kg(O2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2O2</td>
<td>2.1</td>
</tr>
<tr>
<td>LiO2</td>
<td>1.62</td>
</tr>
<tr>
<td>K2O2</td>
<td>2.96</td>
</tr>
<tr>
<td>MgO4</td>
<td>1.84</td>
</tr>
<tr>
<td>CaO4</td>
<td>2.08</td>
</tr>
<tr>
<td>LiClO4</td>
<td>2.8</td>
</tr>
<tr>
<td>KClO4</td>
<td>2.16</td>
</tr>
<tr>
<td>Mg(ClO4)2</td>
<td>1.74</td>
</tr>
</tbody>
</table>

- Allocate an additional 10 kg/kg O2 for packaging, in addition to combustion receptacle (mass TBD)
Electrolytic Oxygen Generation

- Static Feed Water Electrolysis
- Solid Polymer Water Electrolysis
- Water Vapor Electrolysis
- CO2 Electrolysis
**CO₂ Scrubbing Systems**

- **CO₂ production** ~1 kg/person-day
- **Lithium hydroxide (LiOH) absorption**
  - Change out canisters as they reach saturation
  - 2.1 kg/kg CO₂ absorbed
  - Also works with Ca(OH)₂, Li₂O, KO₂, KO₃
- **Molecular sieves (e.g., zeolites)**
  - Porous on the molecular level
  - Voids sized to pass O₂, N₂; trap CO₂, H₂O
  - Heat to 350°-400°C to regenerate
  - 30 kg/kg-day of CO₂ removal; 200W
Nonregenerable CO2 Absorbers

<table>
<thead>
<tr>
<th>Material</th>
<th>kg(material)/kg(CO2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LiOH</td>
<td>1.09</td>
</tr>
<tr>
<td>Ca(OH)2</td>
<td>2.05</td>
</tr>
</tbody>
</table>

- Allocate an additional 1.0 kg/kg(CO2) for packaging
- Only works down to PPCO2 levels of ~0.5 kPa
**CO₂ Regenerable Scrubbing Systems**

- **CO₂ production ~1 kg/person-day**

- **4-Bed Molecular Sieves (4BMS)**
  - Dual paths (one scrubbing, one regenerating)
  - Desiccant bed for moisture removal, 5 A zeolite sieve for CO₂
  - Heat to 350°-400°C to regenerate
  - 30 kg; 0.11 m³; 170 W (all per kg-day of CO₂ removal)

- **2-Bed Molecular Sieves (2BMS)**
  - Carbon molecular sieve for CO₂
  - 16 kg; 0.09 m³; 77 W (per kg/day CO₂)
**CO₂ Regenerable Scrubbing Systems**

- **Solid Amine Water Desorption (SAWD)**
  - Amine resin absorbs H₂O and CO₂; steam heat regenerates
    - Amine + H₂O → Amine-H₂O (hydrated amine)
    - Amine-H₂O + CO₂ → Amine-H₂CO₃ (bicarbonate)
    - Amine-H₂CO₃ + steam → Amine + H₂O + CO₂
  - 17 kg; 0.07 m³; 150 W (all per kg-day of CO₂ removal)
**CO₂ Regenerable Scrubbing Systems**

- Electrochemical Depolarization Concentration (EDC)
  - Uses fuel-cell type reaction to concentrate CO2 at the anode
  - \( CO₂ + \frac{1}{2}O₂ + H₂ \rightarrow CO₂ + H₂O + \text{electricity} + \text{heat} \)
  - CO₂ and H₂ are collected at anode and directed to CO₂ recycling system (combustible mixture!)
  - 11 kg; 0.02 m³; 60 W (all per kg-day of CO₂ removal); does not include reactants for power output
CO2 Membrane Removal Systems

• Osmotic membranes
  - Poor gas selectivity
  - Returns CO2 to cabin air

• Electroactive carriers
  - Electroactive molecules act as CO2 “pump”
  - Very early in development

• Metal Oxides
  - AgO2 absorbs CO2 (0.12 kg O2/kg AgO2)
  - Regenerate at 140°C for 8 hrs (1 kW) - 50-60 cycles
  - Replacing LiOH in EMUs for ISS
**CO₂ Reduction**

- **Sabatier reaction**
  - \( CO₂ + 4H₂ \rightarrow CH₄ + 2H₂O \)
  - Lowest temperature (250°-300°C) with Ni catalyst
  - Electrolyze \( H₂O \) to get \( H₂ \), find use for \( CH₄ \)
  - 91 kg; 3 m³; 260 W (all per kg-day of \( CO₂ \) removal)

- **Bosch reaction**
  - \( CO₂ + 2H₂ \rightarrow C + 2H₂O \)
  - 1030°C with Fe catalyst
  - \( C \) residue hard to deal with (contaminates catalyst)
  - 700 kg; 3.9 m³; 1650 W (all per kg-day of \( CO₂ \) removal)
CO₂ Reduction

- Advance Carbon-formation Reactor System (ACRS)
  - CH₄ → C + 2H₂
  - Lowest temperature (250°-300°C) with Ni catalyst
  - Electrolyze H₂O to get H₂, find use for CH₄
  - 60 kg; 0.1 m³; 130 W (all per kg-day of CO₂ removal)
Nitrogen Makeup

- Nitrogen lost to airlock purges, leakage (can be >1%/day)
- Need to replenish $N_2$ to maintain total atmospheric pressure
- Choices:
  - High pressure (4500 psi) $N_2$ gas bottles
  - Cryogenic liquid nitrogen
  - Storable nitrogen-bearing compounds ($NH_3$, $N_2O$, $N_2H_4$)
Trace Contaminant Control

- Particulate Filters (dusts and aerosols)
- Activated Charcoal (high molecular weight contaminants)
- Chemisorbant Beds (nitrogen and sulphur compounds, halogens and metal hybrids)
- Catalytic Burners (oxidize contaminants that can’t be absorbed)
- 100 kg; 0.3 m³; 150 W (all per person-day)
Water Management

• Distillation Processes
  - Vapor Compression Distillation (VCD)
  - Thermoelectric Integrated Membrane Evaporation (TIMES)
  - Vapor Phase Catalytic Ammonia Removal (VAPCAR)
  - Air Evaporation

• Filtration Processes
  - Reverse Osmosis (RO)
  - Multifiltration (MF)
  - Electrodialysis
Water Distillation

- **Vapor Compression Distillation (VCD)**
  - 300 kg; 1.5 m³; 350 W (for 100 kg H₂O processed per day)

- **VAPCAR**
  - 550 kg; 2.0 m³; 800 W (for 100 kg H₂O processed per day)

- **TIMES**
  - 350 kg; 1.2 m³; 850 W (for 100 kg H₂O processed per day)
Water Revitalization Processes

Waste Management Processes

Bioregenerative Life Support Schematic

Life Support Systems Analysis (example)

Mercury ECLSS Schematic
Figure 31. Gemini ECLSS schematic. (6)
References