Life Support Systems during Space Missions

The Human Perspective

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• Human body needs
• Methods for life support systems: "Open-loop" vs. "Closed-loop"
• Guide for life support systems design
• Ecological (Regenerative) life support system
• Terraforming
Definitions

• **NASA**
  – ECLSS = Environmental Control and Life Support System
  – ECLSS is a group of devices that allow a human being to survive during a space mission

• **Scientific**
  – CELSS = Controlled (or Closed) Ecological Life Support Systems
  – CELSS are a type of scientific endeavor to create a self-supporting life support system

• **In this lecture**
  – LSS = Life Support System
Biological Systems are Complex

• **Biosphere 2** was a test site for prototyping sealed (closed) life support systems to better model how Earth’s ecosystems actually work.

• As a large glass building resembling a giant terrarium in the Arizona desert, this system had **severe problems** maintaining the atmosphere levels and food required for a 8-person crew.
Environment Components

- The Earth’s **atmosphere** is made up of:
  - 78% Nitrogen (N\textsubscript{2})
  - 21% Oxygen (O\textsubscript{2})
  - 0.5% Water vapor
  - Along with very small amounts of Argon, CO\textsubscript{2}, Neon, Helium, Krypton, Xenon, Hydrogen, Methane, and other trace gases

- We depend on the correct **mixture** of gases in the atmosphere to sustain our lives

- We also depend on the **pressure** of our atmosphere to be able to breathe. At sea level, atmospheric pressure is:
  
  \[1 \text{ atm} = 760 \text{ mmHg} = 101.1 \text{ kPa} = 14.7 \text{ pounds per square inch (psi)}\]

- Space travelers must carry their own pressurized atmosphere with the correct mixture of gas
Life Support System

Cabin Atmosphere

• Trade-Offs
  – Atmospheric pressure, O₂, CO₂, etc.
  – Cabin atmosphere vs. EVA
  – Safe, clean air vs. contaminants

• Cabin—Total pressure and pO₂
  – Mercury, Gemini, and early Apollo: 5 psi, 100% O₂ (pO₂ = 260 mmHg); pre-breathed O₂ for 3 hrs prior to launch
  – Skylab: 5 psi, 70% O₂ (pO₂ = 180 mmHg)
  – Space Shuttle: sea-level = 14.7 psi, 21% O₂ (pO₂ = 162 mmHg)
  – Mir/ISS: sea-level = 14.7 psi (1 atm or 760 mmHg), 21% O₂

• Degraded Conditions or Emergencies

<table>
<thead>
<tr>
<th></th>
<th>Operational</th>
<th>90-day</th>
<th>28-day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>760 ± 10 mmHg</td>
<td>same</td>
<td>same</td>
</tr>
<tr>
<td>O₂</td>
<td>146-173 mmHg</td>
<td>124-178</td>
<td>119-178</td>
</tr>
<tr>
<td>CO₂</td>
<td>3 mmHg max</td>
<td>7.6 max</td>
<td>12 max</td>
</tr>
<tr>
<td>Humidity</td>
<td>25-70%</td>
<td>25-75%</td>
<td>25-75%</td>
</tr>
</tbody>
</table>
Lack of Oxygen (Hypoxia)

- The human body is a heat engine that consumes the fuels of carbohydrates, fats, and proteins from food by the chemical process of oxidation, which requires the presence of Oxygen.

- **Symptoms of lack of Oxygen**, or hypoxia, are:
  - Incapability to exercise judgment by comparing and analyzing alternatives
  - Inability to integrate different sensory inputs, resulting in decrement in motor control and coordination
  - Memory troubles
  - Degradation of peripheral and central vision (undetected)
  - Feelings of well-being, drowsiness, nonchalance, and a false sense of security (the last thing a person believes to be necessary is additional oxygen)
**CO₂ Retention (Hypercapnia)**

- **CO₂** is a result of the breakdown of glucose ($C_6H_{12}O_6$) during the aerobic cell respiration process.

- **Excess of CO₂** (Hypercapnia) is caused by exposure to environments containing abnormally high concentrations of carbon dioxide, or by rebreathing exhaled carbon dioxide.

- Symptoms of hypercapnia include:
  - Headache
  - Confusion
  - Drowsiness
  - Elevation in arterial blood pressure
  - Cardiac arrhythmias
  - Disorientation
  - Panic
Nitrogen and "the Bends"

• Although **Nitrogen** makes up more than 70% of the normal atmosphere, too much or too little Nitrogen causes trouble

• When the body is subjected to a sudden **loss of pressure** (divers, aviators) nitrogen dissolved in the blood and tissues can come out of solution and form tiny bubbles

• The Nitrogen gas bubbles tend to congregate in the arm and leg joints where their presence creates pain ("the bends")

• **Space suits** operate at a pressure of 5 psi while the spacecraft are at 14.7 psi. Bends are possible in case of rapid decompression

• **Before EVA**, astronauts spend 3 hours breathing pure Oxygen to flush all of the Nitrogen from their bodies (less if they exercise)
Spacecraft Environment

• Because spacecrafts are completely closed environments, \( \text{CO}_2 \) must be actively removed from the atmosphere. High \( \text{CO}_2 \) levels increase heart rate and respiration rate and cause problems with the acid-base balance of the body.

  \( \text{CO}_2 \) level should be lower than 0.3 % (3 mmHg)

• High **humidity** can promote the rapid growth of microbes or fungus. Low humidity can cause drying of the eyes and skin and the mucous membranes of the nose and throat, thus providing less protection against respiratory infections.

  Water vapor pressure should range from 0.12-0.27 psi (0.01 atm)

• **Temperature** is an important aspect of the body heat balance.

  Temperature should range from 18-27°C (64-81°F)
Loss of Pressure

- Due to collision with debris or mechanical systems failure
- Response time depends on rate of pressure loss:
  - Size of breach, initial module pressure/volume, ability of environmental control system to compensate
- Access to emergency breathing equipment
- Time of Useful Consciousness (TUC)

<table>
<thead>
<tr>
<th>Pressure (kPa)</th>
<th>Equivalent Altitude (m)</th>
<th>TUC</th>
</tr>
</thead>
<tbody>
<tr>
<td>50.8</td>
<td>5486</td>
<td>20-30 min</td>
</tr>
<tr>
<td>42.7</td>
<td>6706</td>
<td>10 min</td>
</tr>
<tr>
<td>37.3</td>
<td>7620</td>
<td>3-5 min</td>
</tr>
<tr>
<td>32</td>
<td>8534</td>
<td>2.5-3 min</td>
</tr>
<tr>
<td>30.1</td>
<td>9144</td>
<td>1-2 min</td>
</tr>
<tr>
<td>23.7</td>
<td>10668</td>
<td>0.5-1 min</td>
</tr>
<tr>
<td>18.8</td>
<td>12192</td>
<td>15-20 sec</td>
</tr>
<tr>
<td>15.9</td>
<td>13106</td>
<td>12-15 sec</td>
</tr>
<tr>
<td>11.6</td>
<td>15240</td>
<td>9-12 sec</td>
</tr>
</tbody>
</table>
## Human Body Needs

<table>
<thead>
<tr>
<th></th>
<th><strong>One day</strong> (per person)</th>
<th><strong>One year</strong> (per person)</th>
<th><strong>% of total mass</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inputs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxygen</td>
<td>0.83 kg</td>
<td>303 kg</td>
<td>2.7 %</td>
</tr>
<tr>
<td>Food</td>
<td>0.62 kg</td>
<td>226 kg</td>
<td>2.0 %</td>
</tr>
<tr>
<td>Potable Water</td>
<td>3.56 kg</td>
<td>1300 kg</td>
<td>11.4 %</td>
</tr>
<tr>
<td>(drink and food prep.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hygiene Water</td>
<td>26.0 kg</td>
<td>9490 kg</td>
<td>83.9 %</td>
</tr>
<tr>
<td>(hygiene, flush, laundry, dishes)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>31.0 kg</td>
<td>≈11400 kg</td>
<td>100 %</td>
</tr>
</tbody>
</table>

| **Outputs**          |                          |                           |                     |
| Carbon dioxide       | 1.0 kg                   | 363 kg                    | 3.2 %               |
| Metabolic solids     | 0.1 kg                   | 36 kg                     | 0.3 %               |
| Water                | 30.0 kg                  | 10950 kg                  | 96.5%               |
| (metabolic / urine)  |                          |                           | 12.3%               |
| (hygiene / flush)    |                          |                           | 24.7%               |
| (laundry / dish)     |                          |                           | 55.7%               |
| (latent)             |                          |                           | 3.6%                |
| **Total**            | 31.0 kg                  | ≈11400 kg                 | 100 %               |
Human Needs re-Temperature

- Human food, oxygen, and water needs vary as a function of temperature
- Classical triad of lethal "Heat Stroke"
  - Core temperature greater than 40.5°C (104.9°K)
  - Disorder of central nervous system (brain stem)
  - Lack of sweating
Contaminants — Sources

• Early examples
  – Apollo 1 (1967) — Fire
  – Apollo 10 (1969) — Fiberglass insulation
  – Apollo 13 (1970) — CO₂ build-up
  – Apollo 18 (1975) — Propellants on reentry entered via vents
  – Soyuz 21 - Salyut 5 (1976) — Acrid odor
  – Soyuz 24 - Salyut 5 (1977) — Flushed air before entry

• Space Shuttle
  – Eye irritation from LiOH canisters and payload chemicals
  – Waste system release of “brown dust”
  – Formaldehyde and Ammonia from overheated refrigerator motor

• Mir
  – O₂, CO₂, ethylene glycol, fumes / fires

Changing CO₂ canisters on board the Space Shuttle
Contaminants — Issues

• **Chemical contamination**
  – Can be brought in **from outside** the spacecraft, e.g. propellants & Freon 21 following an EVA
  – Can come **from inside**, e.g. dust mites, protozoa, fungi (bacteria not contaminants)

• **Spacecraft Maximum Allowable Concentrations (SMACs)**
  – Low toxic effects, acceptable, e.g. slight irritation, mild headache, etc.
  – Medium toxic effects, unacceptable, e.g. blindness, disability, anesthesia, etc.
  – Lifetime risk < 0.01% / mission

• **Monitoring**
  – Shuttle monitored after each mission (gas chromatography / mass spectrometry)
  – ISS — weekly on-orbit, real-time monitoring

*On-board microbio analysis*
• **Considerations**
  – Electrical systems serve as potential ignition sources
  – Inadequate gas mixing may lead to pockets of enriched oxygen
  – Must prepare for direct injuries
  – Combustion events expected to produce toxic pyrolysis products
  – Toxicity of fire suppressants; ability of atmosphere control system to scrub

• **Countermeasures**
  – Strategically placed emergency breathing gear
  – Emergency response protocol; plan for module isolation
  – Refuges: modules, suits, etc.
  – Medical treatment for thermal injuries

*Flame forms a sphere in microgravity*
Major LSS Functions

- **Atmosphere control**
  - Gas storage, recovery and generation
  - CO$_2$ removal
  - Trace contaminant monitoring and removal

- **Temperature and humidity control**
  - Cabin ventilation
  - Equipment cooling

- **Water and food management**
  - Processing, storage and distribution
  - Microbial control

- **Waste management**
  - Collection and storage of human waste
  - Trash

- **Crew safety**
  - Fire detection and suppression
  - Radiation shielding
### Atmosphere revitalization
- **CO₂ removal**
- **O₂ production**
- **Trace contaminant monitoring and control**
- **Microorganism control**
- **Atmosphere control and supply**
- **Monitoring major atmosphere constituents**
- **Atmosphere constituent storage**
- **Pressure control**
- **Temperature control**
- **Humidity control**
- **Ventilation**
- **Equipment cooling**

### Water recovery /management
- **Water storage & distribution**
- **Water production**
- **Water recovery**
- **Water quality monitoring**

### Waste management
- **Collection and stabilisation**
- **Treatment and degradation**
- **Recycling of degradation products**

### Fire detection and suppression
- **Detection of fires**
- **Suppression of fires**
- **Cleanup after a fire**

### Other functions
- **Food storage and preparation**
- **Plant growth facilities**
- **Nutritional control**
- **Radiation protection**
- **Dust removal**
- **Thermally conditioned storage**
- **Habitability**

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**Mission Duration = 1-12 hours**
**Mission Duration = 1-7 days**

<table>
<thead>
<tr>
<th>Atmosphere revitalization</th>
<th>Water recovery /management</th>
<th>Other functions</th>
</tr>
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<tbody>
<tr>
<td>- CO₂ removal</td>
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</tr>
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<td>- Water quality monitoring</td>
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<tr>
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<td>- Dust removal</td>
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<tr>
<td>- Atmosphere control and</td>
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<td>- Thermally conditioned storage</td>
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<td>supply</td>
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<td>- Habitability</td>
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<td>- Monitoring major</td>
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<tr>
<td>- Pressure control</td>
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**Waste management**

- Collection and stabilisation
- Treatment and degradation
- Recycling of degradation products

**Fire detection and suppression**

- Detection of fires
- Suppression of fires
- Cleanup after a fire
## Life Support System

### Mission = 12 days-3 months

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<tr>
<td>• Equipment cooling</td>
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</tr>
</tbody>
</table>

### Atmosphere control

- CO₂ removal
- O₂ production
- Trace contaminant monitoring and control
- Microorganism control
- Atmosphere control and supply
- Monitoring major atmosphere constituents
- Atmosphere constituent storage
- Pressure control
- Temperature control
- Humidity control
- Ventilation
- Equipment cooling

### Water recovery /management

- Water storage & distribution
- Water production
- Water recovery
- Water quality monitoring

### Waste management

- Collection and stabilisation
- Treatment and degradation
- Recycling of degradation products

### Fire detection and suppression

- Detection of fires
- Suppression of fires
- Cleanup after a fire
Mission = 3 months-3 years

**Atmosphere revitalization**
- CO₂ removal
- O₂ production
- Trace contaminant monitoring and control
- Microorganism control
- Atmosphere control and supply
- Monitoring major atmosphere constituents
- Atmosphere constituent storage
- Pressure control
- Temperature control
- Humidity control
- Ventilation
- Equipment cooling

**Water recovery /management**
- Water storage & distribution
- Water production
- Water recovery
- Water quality monitoring

**Waste management**
- Collection and stabilisation
- Treatment and degradation
- Recycling of degradation products

**Fire detection and suppression**
- Detection of fires
- Suppression of fires
- Cleanup after a fire

**Other functions**
- Food storage and preparation
- Plant growth facilities
- Nutritional control
- Radiation protection
- Dust removal
- Thermally conditioned storage
- Habitability
**Open-Loop** Life Support Systems use resources being *brought* from Earth:

- Require continuous input and output
- Technically simple
- Reliable
- But amount of resources is a (linear) function of mission duration

**Closed-Loop** Life Support Systems *recycle* waste into useful resources:

- Amount of resources is independent of mission duration
- High mass
- High power and thermal demand
- Technology less mature
- Less reliable
• **Mass** is not a proper criteria to choose a type of LSS

• The comparison between closed-loop and open-loop system must take into account the differences in **power consumption** and in **rejected heat** which will have to be removed by the thermal control system

use of so-called "**Equivalent mass**"

**Equivalent mass** = Subsystem Mass  
+ Power × Conversion factor for PSS  
+ Power × Conversion factor for TCS

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Note:  
PSS = Power Supplying System
TCS = Thermal Control System
• **Equivalent Mass** as a function of *mission duration*:
Life Support System

Resupply Reduction

Water storage on the ISS
• Russia’s space station Mir recycled cosmonaut’s sweat and water that condensed from exhaled air

• Since May 2009, astronauts aboard the ISS drink water that has been recycled from their sweat and urine

• The $250 million urine recycling system uses a process of distillation (with artificial gravity), filtration, ionization and oxidization "to turn yesterday's coffee into today's coffee"

• This water recovery system is expected to cut the need to carry up water onboard the ISS by 65%
Closed-Loop LSS

- They can use **Physical-Chemical** methods:
  - E.g. mechanical (fans, filters), physical, or chemical principles for separation or concentration process
  - Well understood
  - Relatively reliable and compact
  - Relatively low level of maintenance
  - Quick response time
  - Require less power

- or **Biological (Bioregenerative)** methods:
  - E.g. living organisms such as bacteria and plants to produce (food) or destroy organic molecules
  - Less understood
  - Have large initial volume and mass
  - Slow response time
  - Require more power and maintenance
### Methods Used for LSS

<table>
<thead>
<tr>
<th>Category</th>
<th>Physico-Chemical</th>
<th>Biological</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Food</strong></td>
<td>Stowage and Resupply</td>
<td>Photosynthesis</td>
</tr>
<tr>
<td><strong>Oxygen</strong></td>
<td>Electrolysis</td>
<td>Photosynthesis</td>
</tr>
<tr>
<td></td>
<td>Chlorate Candles</td>
<td></td>
</tr>
<tr>
<td><strong>CO₂ Removal</strong></td>
<td>LiOH</td>
<td>Photosynthesis</td>
</tr>
<tr>
<td></td>
<td>Regenerable Amines</td>
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<tr>
<td></td>
<td>Molecular Sieves</td>
<td></td>
</tr>
<tr>
<td><strong>CO₂ Reduction</strong></td>
<td>Bosch / Sabatier</td>
<td>Photosynthesis</td>
</tr>
<tr>
<td></td>
<td>(\text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O})</td>
<td></td>
</tr>
<tr>
<td><strong>Liquid Wastes</strong></td>
<td>Multi-Filtration</td>
<td>Microbiological</td>
</tr>
<tr>
<td></td>
<td>Evaporation</td>
<td>Respiration</td>
</tr>
<tr>
<td></td>
<td>Vapor Compression</td>
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</tr>
<tr>
<td></td>
<td>Distillation</td>
<td></td>
</tr>
<tr>
<td><strong>Solid Wastes</strong></td>
<td>Incineration</td>
<td>Microbiological</td>
</tr>
<tr>
<td></td>
<td>Supercritical Oxidation</td>
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</tr>
</tbody>
</table>
Guide for LSS Design

• **Safety**
  – Assume that every failure is possible (every valve will leak, every electrical cable will short, every motor will seize and overheat, and every sensor will relay a false signal)
  – Assume that every design will suffer two failures simultaneously

• **Reliability**
  – LSS must be designed to work flawlessly throughout their operational lifetime to ensure crew survivability

• **Think zero-g**
  – Processes such as phase separation (solid, liquid, and gas), heat transfer and heat rejection are of particular concern
  – Air circulation must be organized
• **Spacecrafts are closed chambers**
  – Dilution is never the solution to pollution
  – Everything that is utilized is a consumable
  – Everything that is produced is a product (you can't ignore any waste product)

• **Hazardous gases are very difficult to handle**
  – For example, hydrogen lines are all operated at less than ambient pressure to promote in-leakage, and hydrogen is never stored or allowed to accumulate in any appreciable amount

• **Wastes**
  – Generation of wastes is a source of contamination by noxious and toxic gases, as well as by microbes. Wastes must be processed
Guide for LSS Design

• **Closed systems are complex**
  – The design and operation of LSS must take care of integration and interaction with other systems

• **Simplicity** in operation, maintenance, repair, and control are of prime importance in a flight environment
  – Troubleshooting in a flight environment is often more expensive than the entire cost of design, development, manufacture, and testing of the physical hardware

• **Human factors and human interfaces**
  – Avoid hot surfaces, sharp edges, and exposed rotating equipment
  – Architecture must consider relative location of the different systems, changes in crew posture in microgravity (affecting line of sight and reach), display orientation, and other visual cues
Issues for CELSS

• Closed Environmental/Ecological Life Support System (CELSS): facilities for generating and recycling food, nutrients, atmosphere, and potable water

• Duplicate the functions of the Earth in terms of human life support, without the benefit of the Earth's large buffers—oceans, atmosphere, land masses

• Main question is of how small can the requisite buffers be and yet maintain extremely high reliability over long periods of time in a hostile environment

• Space-based systems must be small, therefore must exercise high degree of control (sensors technology)

• ISRU: In-Situ Resources Utilization
Life Support System

Earth Ecosystem
Role of Plants

From: *Biology, An Everyday Experience*
Kaskel, Hummer & Daniel,
Macmillan/McGraw-Hill, 1995

**Plants**

*Photosynthesis*:
\[ \text{CO}_2 + 2\text{H}_2\text{O} + \text{light} \rightarrow (\text{CH}_2\text{O}) + \text{O}_2 \]

*Respiration*:
\[ \text{CH}_2\text{O} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} \]

Waste water → Clean water

**Humans**

\[ (\text{CH}_2\text{O}) + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} \]

Clean water → Waste water
Humans in Closed-Loop Systems

- Ground-based CELSS currently tested with animals. 90% self-regulated
- MELISSA (*Micro-Ecological Life Support System Alternative*) to be tested with humans in Concordia Station (Antarctic)
- Issues: some bacteria used in this system could be affected by space radiation
Selecting Crops

• **Some factors** for consideration of plants as food crops:
  – Dependable yield
  – High edible biomass yield
  – Small size
  – Dietary variety
  – Nutritionally complete
  – May be genetically modified to increase nutrient content

• **Possible crops** for life support:
  
  Wheat   Rice   Tomato
  Soybean Dry Bean Carrot
  Potato Peanut Cabbage
  Sweetpotatoe Lettuce Radish
### Essential Elements

<table>
<thead>
<tr>
<th>Plants</th>
<th>Humans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>Potassium</td>
<td>Potassium</td>
</tr>
<tr>
<td>Calcium</td>
<td>Calcium</td>
</tr>
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<td>Magnesium</td>
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<td>Phosphorus</td>
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<td>Manganese</td>
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<td>Zinc</td>
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<tr>
<td>Nickel</td>
<td>Nickel</td>
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<tr>
<td>Boron</td>
<td>Sodium</td>
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<td>Arsenic</td>
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<td></td>
<td>Vanadium</td>
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<td>Tin</td>
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</table>

Humans require more micronutrients and have a high sodium requirement in comparison to plants.
Issues for Plants in CELSS

- Light spectrum
- Light intensity
- Light duration
- Reduced air pressure
- Gas production (ethylene)
- Watering

Chlorophyll Absorption

Human Vision
• **Bios-3** was used to conduct 10 closure experiments with 1-3 crewmembers. The longest experiment with 3-human crew was 180 days (1972-1973)

• «Bios-3» included complete regeneration of air and water, as well as partial regeneration of (plant only) food

• Results showed that:
  - At least 13-14 m$^2$ of plant area is needed to fully supply one person with Oxygen, water and 30-40% of food needs (cucumbers, tomatoes, peas, beans, carrots, radish, potatoes, etc.) under the flux of photosynthetically active radiation with an intensity of about 150 W/m$^2$
• For two years, the 8-person crew of Biosphere-2 lived sealed within a 12,000 m\(^2\) mini-world, complete with a tropical rain forest, savanna, marsh, desert, ocean, and working farm.

• After close-up, the oxygen concentration fell from its initial level of 21% by volume, at a rate about 0.5% a month. CO\(_2\) concentration rose, too, but stabilized around 4,000 ppm on its own.

• After a year the crew was showing signs of distress. After 16 months, oxygen concentration had dropped to 14%, the equivalent of breathing air at 4,360-m elevation. The Biospherians could not thrive in such low oxygen. A medical emergency was at hand, and Biosphere-2's project managers decided to pump in a total 15.7 tons of pure oxygen. Though oxygen levels resumed their decline after each of three additions, the crew was able to recover and finish the final eight months of their mission.
To determine the optimal growing conditions when using the same conditions of light, temperature, CO\(_2\) concentration, water and nutrient availability as would be necessary on a lunar or Martian settlement.

Intensive wheat growth in the NASA KSC Biomass Production Chamber. The chamber provides 20 m\(^2\) of growing area in a closed 113 m\(^3\) atmospheric volume.
C.E.B.A.S.: Closed Equilibrated Biological Aquatic System, developed by OHB System, Bremen (Germany)

- Fresh water habitat allowing incubation of various aquatic species (swordtail fish, ciclid fish, pond snail, hornweed plant) in an artificial ecosystem
- Oxygen regulated thanks to plants photosynthesis by switching lamps on when low oxygen
- Flown successfully on:
  - STS-89 (Jan´98)
  - STS-90 (Apr´98)
  - STS-107 (Jan´03)
Paragon Inc., Tucson (Arizona) designed and built the experimental aquatic biosphere now on ISS.

The aquatic biosphere is a passively controlled, materially closed, bioregenerative life support system for long-duration experiments in space.

It provides for long-term growth and breeding of aquatic plants, including the small red shrimp *Halocaridina rubra*, snails and several species of small crustacea.
Life Support System

Terraforming

- Changing the temperature and atmosphere of a planet to create more Earth-like conditions
- Models show that a sustained change of 4°C in the temperature at the Martian south pole can initiate a runaway greenhouse effect that will result in the evaporation of the polar cap (Zubrin, 1996)
- An atmosphere of 100 mbar could be obtained in 25 years
- Humans would no longer require space suits and would wear scuba-type breathing gear
- Simple plants would use the CO$_2$ and introduce Oxygen in increasingly breathable quantities
• Methods for accomplishing global warming of Mars regions include:
  – Orbiting mirrors (125-km radius)
  – Factories producing large amount of CFCs
  – The help of bacteria (Sagan, 1961)
Summary

- **Closed-loop** – except energy, no material needed to be added to the system for it to function

- **Bio-regenerative** – everything recycled biologically instead of through physical or chemicals means

- **Non-polluting** – does not result in any toxic byproducts

- **Self-sustaining** – productive & functions independently for long period of time

- **Intensive agriculture system** – high yields with diverse crops

- **Pathogen-free** – "good" bacteria only

*Star Trek* food synthesizer
Conclusions

• Until all aspects of closed ecological life-support system are better known during the conditions of space flight, the best solution for a life support system is hybrid, i.e. a combination of physical-chemical and bioregenerative methods.

• The evaluation of the Life Support System for a space mission includes multiple factors, such as:
  – Mission duration
  – System mass
  – Reliability
  – Maintainability
  – Power and thermal cost
  – As well as the number of interfaces with other systems and subsystems


• [http://advlifesupport.jsc.nasa.gov/](http://advlifesupport.jsc.nasa.gov/)

• [http://science.howstuffworks.com/space-shuttle5.htm](http://science.howstuffworks.com/space-shuttle5.htm)