Study on the Survivability and Adaptation of Humans to Long-Duration Interplanetary and Planetary Environments

WP 4200

Advanced LSS:
Bioregenerative Life Support Developments

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HUMEX WP 4200

Final Presentation

ESTEC, 30 May 2001

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INPUTS coming from WP 2100 and 2200

• Missions and scenarios definitions
• Crew requirements and crew waste production

INPUTS coming from the state of the art

• BLSS technologies
• BLSS international projects

WP 4200 ACHIEVEMENTS

OUTPUTS

The Biological Subsystems for LSS
Evaluation of Bioregenerative Life Support Systems for the 3 scenarios
Recommendations for future research on Earth and in space environment
Life Support System requirements and constraints

The Biological Subsystems

Evaluation of Bioregenerative Life Support Systems for the 3 scenarios

Recommendations for future research on Earth and in space environment
Basic requirements

Needs
(30 kg/day.man)
value depend on hygiene

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<tbody>
<tr>
<td>O₂</td>
<td>3%</td>
</tr>
<tr>
<td>Hygiene water</td>
<td>78%</td>
</tr>
<tr>
<td>Potable water</td>
<td>9%</td>
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<tr>
<td>Food</td>
<td>9%</td>
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Waste

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<tr>
<td>CO₂</td>
<td>4%</td>
</tr>
<tr>
<td>Solid Human waste</td>
<td>5%</td>
</tr>
<tr>
<td>Liquid waste</td>
<td>81%</td>
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<tr>
<td>Perspiration</td>
<td>10%</td>
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Missions overview

Scenario 1: Lunar base on the south pole
Moon stay 180 days
Fly 6-10 days

Scenario 2: Mars mission 1000
Mars stay 525 days
Fly 418 days

Scenario 3: Mars mission 500
Mars stay 30 days
Fly 420 days

Criteria:
- duration
- location
### General features of LSS

| **Food management** | - food production: higher plants chambers; single cell protein production  
|                     | - food preparation  
|                     | - storage  
|                     | - nutritional and microbial quality control, monitoring and management  |
| **Water management** | - drinking water production (control/monitoring of microbial quality and composition)  
|                     | - hygiene water recovery and production  
|                     | - water quality control  |
| **Air management**  | - CO₂ removal and O₂ production (atmosphere revitalisation)  
|                     | - air composition control  
|                     | - air quality (microbial/dust) and composition monitoring and control  
|                     | - air pressure control  |
| **Waste management**| - collection and stabilisation of waste (vegetal fibres/feces/urine/…)  
|                     | - treatment and degradation  
|                     | - recycling of degradation products (C, N, P, oligo-elements cycles)  |
| **Environmental protection** | - thermal control  
|                             | - microbial protection against contamination: monitoring and control  
|                             | - radiation protection  
|                             | - microbial contamination of surfaces: monitoring and control  |
## General features of LSS

<table>
<thead>
<tr>
<th>Feature</th>
<th>Details</th>
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<tbody>
<tr>
<td>1. Life Support Systems</td>
<td>to be conceived as an <strong>integrated</strong> sum of unit operations</td>
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<tr>
<td></td>
<td>➤ Technological solutions entirely depend on specific objectives: LSS will be completely different for orbital flight, interplanetary flight, Moon outpost, …</td>
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<td></td>
<td>➤ Generic technologies must be studied and developed</td>
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<td>2. Life Support requires high degree of safety</td>
<td>➤ microbial control</td>
</tr>
<tr>
<td></td>
<td>➤ radiation protection</td>
</tr>
<tr>
<td>3. Life Support requires total reliability</td>
<td>➤ alternative recycling systems in parallel</td>
</tr>
<tr>
<td></td>
<td>➤ complete representation and prediction by deterministic approach</td>
</tr>
<tr>
<td></td>
<td>➤ complete control and self organization of the Life Support system to be carefully assessed</td>
</tr>
<tr>
<td>4. Psychology and ergonomy</td>
<td>to be incorporated in the first steps of study</td>
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<tr>
<th>HUMEX WP 4200</th>
<th>Final Presentation</th>
<th>ESTEC, 30 May 2001</th>
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General features of BLSS

- CREW
- Liquefying compartment
- Nitrifying compartment
- Anaerobic Photoauto/heterotrophic compartment
- IV b: Higher plant compartment
- IV a: Photoautotrophic compartment
- III: Nitrifying compartment
- II: Anaerobic Photoauto/heterotrophic compartment
- Waste
- Biomass
- CO₂
- O₂
- Light
- Volatile fatty acids
- NH₄⁺ CO₂ H₂

Waste

Biomass

CO₂

O₂

Light

Volatile fatty acids

NH₄⁺ CO₂ H₂

Biomass

CO₂

O₂

Light

Volatile fatty acids

NH₄⁺ CO₂ H₂
Bioregenerative systems

Higher plants chambers:

- CO₂ Removal and oxygen producer
- Involved in mineral cycles
- Water recycling - water producer (perspiration)
- Food producer

- Important area (15 - 30 m²)/man
- Low dynamic response systems
- Important production of organic waste (fibre)
Bioregenerative systems

Algae Compartments:

- CO₂ recycling and oxygen producer
- Food complement (vitamins, minerals ?)
- Small volumes.
- Rapid dynamic response
- Controlled bioreactors

Biomass in food limited
Gas Exchange Rate with crew (QP and QR) not balanced
Bioregenerative systems

Micro-organisms:

- Organic matter degradation
- Mineral cycle
- Production of various compounds
- Relatively small volumes
- Various dynamics
- Various operating conditions (aerobic/anaerobic)
- High flexibility (and complexity)
Bioregenerative systems

Yeast/Fungi:
- Organic matter degradation
- Involved in mineral cycles
- Water recycling (?)
- Fibres degradation
- Food producer
- Slow dynamic response
- Unknown control processes

Animals:
- Food source
- Human like constraints and requirements
- Large and advanced BLSS only

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Bioregenerative systems selection criteria

The choice of Biological subsystems for the Life Support Systems for long term missions, depend on two main criteria:

- **The duration of the mission.** The duration is linked to the mass of consumables required to sustain the crew.

- **The distance from Earth of the mission.** The constraints are different for “spacecraft” mission and “land” missions. For spacecraft volume, mass, launch cost, microgravity, energy cost are important, while for largest bases (Moon or Mars) the reliability for very long time and the closure of the systems become the more important elements.
Bioregenerative systems and scenarios

Scenario 1: Lunar base on the south pole

Earth-Moon-Earth transfer:
  • Classical «Shuttle-like » physico-chemical/storage systems

Moon base:
  • Permanent base
  • Continuously running system
  • Step by step building of the LSS, from simple physico-chemical/storage strategy to advanced BLSS
  • Enable the test and evaluation of systems and technologies
Bioregenerative systems and scenarios

Scenario 1: Lunar base on the south pole

**Moon base:**

- Phase 1: atmosphere - water recycling systems (91% of the consummable mass)
  - algae based systems for $O_2/CO_2$ management
  - microbial based systems for waste water/grey water completed by passive physico-chemical and filtration processes

- Phase 2: food production systems
  - higher plants chambers coupled with phase 1 systems
Bioregenerative systems and scenarios

Scenario 3: Mars mission 500 days
   Split of the crew → 2 autonomous systems

Earth-Mars-Earth transfer:
   • Crew of 6 for travel - Crew of 2 in orbit
   • Spacecraft: small volumes/surfaces
     - Subsystems of Moon base phase 1.
     - Possible contribution of higher plants, but to a limited extent (covering 20-30% of the diet?).

   • Possible to expect about 100% of recycling for oxygen and water, and 30-40% for food.
Bioregeneratives systems and scenario

Scenario 3: Mars mission 500 days

*Mars outpost:*

- 30 days mission: problem for the start-up of biological systems

- Physico-chemical/storage strategy probably more adapted, with the possible use of a cargo, what reduce also the problem to only one LSS for the spacecraft.
Bioregeneratives systems and scenario

Scenario 2: Mars mission 1000 days
   Split of the crew: 2 autonomous systems
   Long term mission for both the transfer and the outpost.

*Earth-Mars-Earth transfer:*
   • Same as the 500 days mission

*Mars outpost:*
   • 500 days on Mars: regenerative system required
   • 2 options:
Bioregeneratives systems and scenario

Scenario 2: Mars mission 1000 days

*Mars outpost (2 options):*

- Onboard system (started with the mission from Earth, and part of the LSS used in the transfer phase): problem for the splitting (2/3 - 1/3; 2 autonomous systems);

- System developed on Mars and landing module possess standard physico-chemical/storage for the delay required for the start-up: simple and short dynamic systems more easy to start; infrastructure and material launched by cargo.
Recommendation for future research

- **Higher plants:** core system for food production.
  - difficulty to control their biological activity
  - man power required not in favour of their use for small volumes systems such as spacecraft
  - core of Biological Systems for permanent bases.
  - modelling and understanding required

- **Algae:** very promising for atmosphere regeneration.
  - biomass as food complement (proteins, vitamins)
  - accurate control of the bioprocesses
  - complement for physico/chemical regeneration of atmosphere
  - main problem to be solved concerns the O₂ ratio between consumption and production (Gas Exchange Coefficient).
Recommendation for future research

- **Micro-organisms**: central element of a Biological Life Support System
  - the first step in the treatment of the waste produced by the crew or by the other biological components of the system
  - high closure of the LSS can only be achieved by use of microbial systems

The selection of processes that can be used in terms of species involved, efficiencies, reliability and safety is an important challenge.

Another important point is that these processes are of direct interest for terrestrial application in waste treatment systems (water, isolated bases, self sufficient building…)

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### Recommendation for future research

| Microbial compartments: photosynthetic/anaerobic/aerobic (waste digestion/single cell protein production) | • bioreactors design  
• micro-organisms and strain designs (genetic engineering)  
• metabolism control strategies |
|---|---|
| Higher plant chambers | • crops selection  
• design and optimisation of culture chambers  
• control strategies |
| Vegetal collection and food preparation systems | 
| Physico-chemical systems | • membrane processes (water recovery)  
• chemical processes (CO₂ recycling/O₂ production/lignin degradation)  
• ISRU processes |
| Microbial contaminants | • detection and removal systems |
| Overall control strategies | • sensors technologies (miniaturisation), strategies of control of loop systems and software developments |