Integrated Atmosphere Resource Recovery and Environmental Monitoring Technology Demonstration for Deep Space Exploration

Jay Perry, Morgan Abney, Jim Knox, Keith Parrish, and Monsi Roman
NASA Marshall Space Flight Center

Darrell Jan
NASA Jet Propulsion Laboratory

42nd ICES, 16–19 July 2012, San Diego, California, USA
Technological Advancement Objectives

- To evolve the ISS environmental control and life support (ECLS) system platform to enable deep space exploration
  - Improve reliability & maintainability
  - Reduce consumable mass
- To maximize commonality across missions and vehicles
- To mature process technologies for flight programs
  - Reduce technical risk and cost
- To develop modular resource recovery technologies
What is Atmosphere Revitalization?
Functional Trade Spaces Help Focus Development
### Spacecraft Atmosphere Revitalization Past & Present

<table>
<thead>
<tr>
<th>PROJECT</th>
<th>MISSION DURATION</th>
<th>CABIN VOLUME (m³)</th>
<th>CREW SIZE</th>
<th>TECHNOLOGICAL APPROACH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>34 hours</td>
<td>1.56</td>
<td>1</td>
<td>Atmosphere: 100% O₂ at 34.5 kPa. Atmosphere supply: Gas at 51.7 MPa. CO₂ removal: LiOH. Trace contaminants: Activated carbon.</td>
</tr>
<tr>
<td>Gemini</td>
<td>14 days</td>
<td>2.26</td>
<td>2</td>
<td>Atmosphere: 100% O₂ at 34.5 kPa. Atmosphere: Supercritical storage at 5.86 MPa. CO₂ removal: LiOH. Trace contaminants: Activated carbon.</td>
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<tr>
<td>Apollo</td>
<td>14 days</td>
<td>5.9</td>
<td>3</td>
<td>Atmosphere: 100% O₂ at 34.5 kPa. Atmosphere: Supercritical storage at 6.2 MPa. CO₂ removal: LiOH. Trace contaminants: Activated carbon.</td>
</tr>
<tr>
<td>Skylab</td>
<td>84 days</td>
<td>361</td>
<td>3</td>
<td>Atmosphere: 72% O₂/28% N₂ at 34.5 kPa. Atmosphere supply: Gas at 20.7 MPa. CO₂ removal: Type 13X and 5A molecular sieves regenerated by vacuum swing. Trace contaminants: Activated carbon.</td>
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<tr>
<td>Space Shuttle</td>
<td>14 days</td>
<td>74</td>
<td>7</td>
<td>Atmosphere: 21.7% O₂/78.3% N₂ at 101 kPa. Atmosphere supply: Gas at 22.8 MPa CO₂ removal: LiOH. Trace contaminants: Activated carbon and ambient temperature CO oxidation.</td>
</tr>
<tr>
<td>International Space Station</td>
<td>180 days</td>
<td>Up to 600</td>
<td>3 to 6</td>
<td>Atmosphere: 21.7% O₂/78.3% N₂ at 101 kPa. Atmosphere supply: Gas at 20.7 MPa/water electrolysis CO₂ removal: Silica gel with type 13X and 5A molecular sieves regenerated by vacuum/temperature swing. CO₂ reduction: Sabatier reactor (scar for future addition). Trace contaminants: Activated carbon and thermal catalytic oxidation.</td>
</tr>
</tbody>
</table>
ISS – The “Launch Platform” to Deep Space

• **Reduce:**
  - Logistics requirements
  - Expendable resources
  - Complexity

• **Improve:**
  - Operational robustness
  - Life cycle economics

• **Demonstrate:**
  - More complete loop closure
Strategic Improvements

- **Cabin ventilation**
  - Quiet fan design principles
- **Carbon dioxide removal**
  - Durable adsorbent media
  - Process air drying
- **Trace contaminant control**
  - Alternative high capacity adsorbent media
  - Structured oxidation catalysts
  - Low maintenance particulate filtration & disposal
- **Oxygen supply**
  - Long-lived electrolysis cell stack materials
  - Alternative process control approaches
- **Oxygen recovery**
  - Reduction byproduct processing
- **Environmental monitoring**
  - Alternative major constituent monitoring approaches
  - Alternative trace constituent monitoring approaches
  - Microbial & particulate monitoring techniques
ISS Architecture Testing Objectives

- Phase 1A—Demonstrate functional performance of the basic ISS AR subsystem using the CDRA in CO₂ vent mode and the TCCS operating in parallel.
- Phase 1B—Demonstrate the partial functional performance of the basic ISS AR subsystem when operating in a resource recovery mode that includes integration with CO₂ conditioning, storage, and reduction equipment.
- Phase 2—Investigate propagation of trace contaminants through the core ISS AR subsystem equipment with emphasis on the CDRA and CO₂ conditioning and storage equipment.
- Phase 3—Demonstrate the full resource recovery functional performance of the ISS AR subsystem including the CO₂ removal, CO₂ conditioning and storage, CO₂ reduction and post-processing, oxygen generation, and trace contaminant control functions.
Cycle 1 Testing Objectives

- Demonstrate simultaneous sustained operation of oxygen generation, CO₂ removal, trace contaminant control, major constituent monitoring, and CO₂ reduction processes under continuous operating conditions using an ISS-derived process architecture.
- Demonstrate the effect of the control algorithm governing the CO₂ compressor operation (on/off rules) and the CDRA valve sequencing on the overall CO₂ reclamation efficiency for various modes of operation.
- Determine the purity of product CO₂ from the CDRA-4 sorbent beds.
- Determine the purity of product oxygen and hydrogen from the OGA.
- Determine the effect cabin atmosphere leakage and/or atmospheric major constituent inclusion on the CDRA CO₂ product may have on CRA performance.
- Determine the purity of product water from the Sabatier-based CRA.
- Demonstrate CRA post-processing first stage to purify methane.
- Demonstrate oxygen generation alternative process control concept.
Incremental Process Architecture Progression

- **Cycle 1**: Modified ISS architecture incorporating improved trace contaminant and CO$_2$ removal adsorbents; trace contaminant removal oxidation catalysts; partial CO$_2$ reduction byproduct processing; and alternative major atmospheric constituent monitoring.

- **Cycle 2**: Alternative process gas drying equipment; advanced CO$_2$ reduction byproduct processing; and alternative major constituent and volatile organic compound monitoring.

- **Cycle 3**: Advanced CO$_2$ removal and compression; complete CO$_2$ reduction byproduct processing; advanced environmental monitoring sensor array; ammonia catalytic reduction.
Conclusion

- Functional, unit operation-driven approach
  - Focus on ISS ECLS system strengths and weaknesses
  - Use robust design principles to achieve stage-wise optimization
- Leverage core process technologies from existing equipment designs as appropriate
- Attention to design modularity to address commonality across mission and vehicle architectures
Further Reading


