Water Reclamation

- Discussion of term project
- Fundamentals of water reclamation
- Water reclamation
  - Potable
  - Hygiene
  - Urine
- Solids disposal

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Expected Content of Term Project

• Title of project
• Team members
• Design reference mission(s)
  – Where, when, how
• Top-level requirements
  – e.g., Crew size, duration, EVA support, etc.
• Derived requirements
  – e.g., Habitat volume, interfaces, power, etc.
• Design elements
Term Project Design Elements

- Habitat configuration
  - Size, shape, orientation
  - Internal layout (habitable spaces, fixed equipment, etc.)
  - Atmosphere design (total pressure, ppO2)
  - EVA support (suit pressure, denitrogenation, prebreathe times, airlock/crew lock and other interfaces)
  - Rover support (if appropriate)
  - Radiation protection (shielding makeup and configuration)
- CAD expectations: external dimensioned 3-view, detailed interior layouts, external “beauty” image
Term Project Design Elements

• Life support analyses
  – Air reclamation
  – Water recycling
  – Food provision - storage / processing / growth
  – Waste collection and management
  – Air ventilation and handling
  – External stores for life support consumables

• Other topics of interest or necessity
Mechanics of Term Project

• Submission in form of a briefing package (slides, not prose)
  – Package used for 10-minute presentation
  – Full package (no page limit)

• Initial deadline: progress check Wednesday 4/17 (e-mail preferred)
  – Whatever you have completed
  – Prioritize DRM, initial habitat configuration
  – Include cover page with names of team members
  – Will get feedback to support final submission on last day of class 5/9
# ISS Consumables Budget

<table>
<thead>
<tr>
<th>Consumable</th>
<th>Design Load (kg/person-day)</th>
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</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>
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<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>
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</table>
Resupply with Open Loop Life Support

Open-Loop Life Support System
Resupply Mass - 12,000 kg/person-year
(26,500 lbs/person-year)

Water 89%
Oxygen 2.5%
Food (dry) 2.2%
(Hydrated = 7%)
Crew Supplies 2.1%
Gases lost to space 2.1%
Systems Maintenance 2.1%

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%
Water Recovery and Management

Types of Water

• Potable water
  – Drinking and food preparation
  – Organic solids < 500μg/liter
• Hygiene water
  – Washing
  – Organic solids < 10,000 μg/liter
• Grey water (used hygiene water)
• Condensate water (from air system)
• Urine
Water Usage for Various Missions (1)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Devon Island Mars Research Station Study</th>
<th>International Space Station</th>
<th>Transit Vehicle</th>
<th>Early Planetary Base</th>
<th>Mature Planetary Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drinking Water</td>
<td>kg/cm²d</td>
<td>2.59</td>
<td>2.00 (1)</td>
<td>2.00 (2)</td>
<td>2.00 (2)</td>
<td>2.00 (2)</td>
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<tr>
<td>Food Rehydration Water</td>
<td>kg/cm²d</td>
<td>1.03</td>
<td>0.50 (2)</td>
<td>0.50 (2)</td>
<td>0.50 (2)</td>
<td>0.50 (2)</td>
</tr>
<tr>
<td>Total Human Consumption</td>
<td>kg/cm²d</td>
<td>3.62</td>
<td>2.50</td>
<td>2.50</td>
<td>2.50</td>
<td>2.50</td>
</tr>
<tr>
<td>Urinal Flush</td>
<td>kg/cm²d</td>
<td>0</td>
<td>0.30 (1)</td>
<td>0.30 (1)</td>
<td>0.50 (2)</td>
<td>0.50 (2)</td>
</tr>
<tr>
<td>Personal Hygiene</td>
<td>kg/cm²d</td>
<td>0.46 (4)</td>
<td>0.4 (2)</td>
<td>0.4 (2)</td>
<td>0.4 (2)</td>
<td>0.4 (2)</td>
</tr>
<tr>
<td>Hand Wash</td>
<td>kg/cm²d</td>
<td>0.64</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shaving</td>
<td>kg/cm²d</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medical water</td>
<td></td>
<td>5 kg plus 0.5 kg/cm²d (1)</td>
<td>5 kg plus 0.5 kg/cm²d (1)</td>
<td>5 kg plus 0.5 kg/cm²d (1)</td>
<td>5 kg plus 0.5 kg/cm²d (1)</td>
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</tbody>
</table>

Water Usage for Various Missions (2)

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<th>Parameter</th>
<th>Units</th>
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<th>International Space Station</th>
<th>Transit Vehicle</th>
<th>Early Planetary Base</th>
<th>Mature Planetary Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleaning Science &amp; Engineering</td>
<td>kg/CM⁻d</td>
<td>0.08</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shower</td>
<td>kg/CM⁻d</td>
<td>1.08</td>
<td>n/a</td>
<td>n/a</td>
<td>1.08 (8)</td>
<td>1.08 (8)</td>
</tr>
<tr>
<td>Laundry</td>
<td>kg/CM⁻d</td>
<td>1.95</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>1.8 (8)</td>
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<tr>
<td>Dish Wash</td>
<td>kg/CM⁻d</td>
<td>3.54</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>3.54 (8)</td>
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<td>Total Hygiene Consumption</td>
<td>kg/CM⁻d</td>
<td>7.80</td>
<td>0.7</td>
<td>0.7</td>
<td>1.98</td>
<td>7.32</td>
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<tr>
<td>Payload</td>
<td>kg/CM⁻d</td>
<td>2.18 (1)</td>
<td>TBD (1)</td>
<td>TBD (1)</td>
<td>TBD (1)</td>
<td>TBD (1)</td>
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<tr>
<td>Total Payload Consumption</td>
<td>kg/CM⁻d</td>
<td>2.18</td>
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<tr>
<td>Total Water Consumption</td>
<td>kg/CM⁻d</td>
<td>11.42</td>
<td>4.85</td>
<td>3.77</td>
<td>10.17</td>
<td>28.08</td>
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<tr>
<td>Biomass Production Water Consumption</td>
<td>kg/m²⁻d</td>
<td>0.10 (51)</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>4.00</td>
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# Wastewater Generation Rates


<table>
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<tr>
<th>Parameter</th>
<th>Units</th>
<th>International Space Station</th>
<th>Transit Vehicle</th>
<th>Early Planetary Base</th>
<th>Mature Planetary Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urine</td>
<td>kg/CM-d</td>
<td>1.20(1)</td>
<td>1.50(2)</td>
<td>1.50(2)</td>
<td>1.50(2)</td>
</tr>
<tr>
<td>Urinal Flush</td>
<td>kg/CM-d</td>
<td>0.30(1)</td>
<td>0.30(1)</td>
<td>0.50(2)</td>
<td>0.50(2)</td>
</tr>
<tr>
<td><strong>Total Urine Wastewater Load</strong></td>
<td>kg/CM-d</td>
<td>1.50</td>
<td>1.80</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Oral Hygiene</td>
<td>kg/CM-d</td>
<td>n/a</td>
<td>n/a</td>
<td>0.37(2)</td>
<td>0.37(2)</td>
</tr>
<tr>
<td>Hand Wash</td>
<td>kg/CM-d</td>
<td>n/a</td>
<td>n/a</td>
<td>4.08(2)</td>
<td>4.08(2)</td>
</tr>
<tr>
<td>Shower (2)</td>
<td>kg/CM-d</td>
<td>n/a</td>
<td>n/a</td>
<td>2.72(2)</td>
<td>2.72(2)</td>
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<tr>
<td>Laundry</td>
<td>kg/CM-d</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>11.87(3)</td>
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<tr>
<td>Dish Wash</td>
<td>kg/CM-d</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>5.41(3)</td>
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<tr>
<td>Food Preparation and Processing</td>
<td>kg/CM-d</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>TBD</td>
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<tr>
<td><strong>Total Hygiene Wastewater Load</strong></td>
<td>kg/CM-d</td>
<td>0.00</td>
<td>0.00</td>
<td>7.17</td>
<td>24.45+</td>
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<tr>
<td>Crew Latent Humidity Condensate</td>
<td>kg/CM-d</td>
<td>2.27(2)</td>
<td>2.27(2)</td>
<td>2.27(2)</td>
<td>2.90(2)</td>
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<tr>
<td>Animal Latent Humidity Condensate</td>
<td>kg/CM-d</td>
<td>n/a</td>
<td>n/a</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td><strong>Total Latent Wastewater Load</strong></td>
<td>kg/CM-d</td>
<td>2.27</td>
<td>2.27</td>
<td>2.27+</td>
<td>2.90+</td>
</tr>
<tr>
<td>Payload</td>
<td>kg/CM-d</td>
<td>n/a</td>
<td>n/a</td>
<td>TBD(3)</td>
<td>TBD(3)</td>
</tr>
<tr>
<td><strong>Total Payload Wastewater Load</strong></td>
<td>kg/CM-d</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00+</td>
<td>0.00+</td>
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<tr>
<td><strong>Total Wastewater Load</strong></td>
<td>kg/CM-d</td>
<td>3.77(3)</td>
<td>4.07</td>
<td>11.44+</td>
<td>29.35+</td>
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<tr>
<td>Biomass Production Wastewater (ppm)</td>
<td>kg/m²d</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>TBD</td>
</tr>
</tbody>
</table>

Water Reclamation
Potable Water Reclamation Technologies

- Multifiltration
- Reverse Osmosis
- Electrochemical Deionization
Potable Water Multifiltration Schematic
Potable Water Reverse Osmosis Schematic
Close-up of Reverse Osmosis Concept

Electrochemical Deionization Schematic
Hygiene Water Reclamation Technologies

- Multifiltration
- Reverse Osmosis
Hygiene Water Reverse Osmosis Schematic
Multifiltration for Hygiene Water
Urine Reclamation Technologies

- TIMES - Thermoelectric Integrated Membrane Evaporation System
- VCD - Vacuum Compression Distillation
- VPCAR - Vapor Phase Catalytic Ammonia Removal
- AIRE - Air Evaporation
Thermoelectric Integrated Membrane Evaporation System

Vacuum Compression Distillation Schematic
VCD Drum Distillation Schematic

VAPCAR Simplified Schematic

AES - Air Evaporation for Urine Treatment
Water Distillation

• Vapor Compression Distillation (VCD)
  – 300 kg; 1.5 m$^3$; 350 W (for 100 kg H2O processed per day)

• VAPCAR
  – 550 kg; 2.0 m$^3$; 800 W (for 100 kg H2O processed per day)

• TIMES
  – 350 kg; 1.2 m$^3$; 850 W (for 100 kg H2O processed per day)
### Selected Design Parameters


<table>
<thead>
<tr>
<th>Function</th>
<th>technology</th>
<th>mass (kg/CM)</th>
<th>volume (m³/CM)</th>
<th>power (kW/CM)</th>
<th>cooling (kW/CM)</th>
<th>EM (kg/CM)</th>
<th>logistics (kg/CM-yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O₂ generation</td>
<td>SPWE</td>
<td>28.3</td>
<td>0.04</td>
<td>0.37</td>
<td>0.37</td>
<td>173</td>
<td>3.2</td>
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<tr>
<td>CO₂ removal</td>
<td>4BMS</td>
<td>50.3</td>
<td>0.10</td>
<td>0.22</td>
<td>0.22</td>
<td>151</td>
<td>0.0</td>
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<td>CO₂ reduction</td>
<td>Sabatier</td>
<td>4.5</td>
<td>0.19</td>
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<td>Trace contaminant control</td>
<td>charcoal</td>
<td>19.6</td>
<td>0.07</td>
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<td>0.04</td>
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<td>40.8</td>
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<td>Wastewater processing</td>
<td>multifiltration</td>
<td>119.0</td>
<td>0.56</td>
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<td>0.08</td>
<td>268</td>
<td>119.5</td>
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<td>Urine processing</td>
<td>VCD</td>
<td>32.0</td>
<td>0.09</td>
<td>0.02</td>
<td>0.02</td>
<td>60</td>
<td>43.8</td>
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<td>N₂/O₂ storage</td>
<td>tank</td>
<td>272.0</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>272</td>
<td>136.0</td>
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<td>Water storage</td>
<td>tank</td>
<td>26.5</td>
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<td>0.00</td>
<td>0.00</td>
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<td>146</td>
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<tr>
<td></td>
<td>units</td>
<td>kg/kg</td>
<td>kg/m³</td>
<td>kg/kW</td>
<td>kg/kW</td>
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**Table B.1. ISS P/C ECLSS technologies.**
Water System Design Parameters

<table>
<thead>
<tr>
<th>Function/technology</th>
<th>#crew</th>
<th>mass (kg)</th>
<th>volume (m³)</th>
<th>power (kW)</th>
<th>cooling (kW)</th>
<th>90-day resupply mass (kg)</th>
<th>EM (MTV, 400 days) (kg)</th>
<th>TRL</th>
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<tbody>
<tr>
<td>Condensate and hygiene</td>
<td>8</td>
<td>95</td>
<td>0.34</td>
<td>0.35</td>
<td>0.08</td>
<td>50.8</td>
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<td>Multifiltration</td>
<td>8</td>
<td>88</td>
<td>0.50</td>
<td>0.26</td>
<td>0.09</td>
<td>34.5</td>
<td>220</td>
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<tr>
<td>Reverse osmosis</td>
<td>8</td>
<td>59</td>
<td>0.31</td>
<td>0.36</td>
<td></td>
<td></td>
<td>121</td>
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<td>Urine purification</td>
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<tr>
<td>VCD</td>
<td>8</td>
<td>150</td>
<td>0.38</td>
<td>0.18</td>
<td>0.26</td>
<td>421.8</td>
<td>1,090</td>
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<td>TIMES</td>
<td>8</td>
<td>116</td>
<td>0.29</td>
<td>0.33</td>
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<td>AES</td>
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<td>0.25</td>
<td>362.9</td>
<td>4.0</td>
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Solid Waste Disposal Technologies

- Freeze Drying
- Thermal Drying
- Combustion Oxidation
- Wet Oxidation
- Supercritical Water Oxidation
Freeze Drying Schematic
Thermal Drying Schematic
Combustion Oxidation Schematic
Wet Oxidation Schematic

CONTAMINANT VAPOR ABSORPTION

CO2

CONDENSER

CONDENSATE

COOLANT OUT

COOLANT IN

POWER

DRY BOILER

SOLIDS

FEED [WATER & SOLIDS]

HIGH PRESSURE PUMP

OXYGEN COMPRESSOR

OXYGEN

POWER

REACTOR WITH MIXER

Water Reclamation

ENAE 697 - Space Human Factors and Life Support
Supercritical Water Oxidation Schematic
UMd Final MFH Design

- 3.65 m diameter
- 5.5 m tall
- 4:1 ellipsoidal endcaps
- Three module berthing ports (Cx standard)
- Four suitports (two in berthing hatches)
- Inflatable airlock
- All 6063-T6 structure
Lower Deck Layout

- CTB Stowage Racks
- Air Handling/CO₂ Scrubbing/Heat Exchanger
- Multipurpose Table
- Berthing Hatch
- Ladder to Upper Deck
- Water Recycling
Upper Deck Layout

- Individual Crew Berths
- Galley Wall - Food Preparation
- Table and Seats: Opened for Meals, Stowed Otherwise
- CTB Stowage Racks
- Bathroom
MFHE Life Support Requirements

- 4 crew for nominal mission of 28 days
- Additional contingency mission of 30 days
- 8 crew in handoff mode for 48 hours
  - 4 95th percentile American males for 60 days
Lunar Habitat Water Recycling Trades

![Graph showing system mass (kg) over duration (days) for different water recycling methods: H2O/Open Loop, H2O/Condensate, H2O/Cond+Urine.](image)

- **H2O/Open Loop**
- **H2O/Condensate**
- **H2O/Cond+Urine**
Effect of Duration on Life Support

- **7 Day Optimum**
- **28 Day Optimum**
- **180 Day Optimum**

Duration (days) vs System Mass (kg)

- Axes:
  - Y-axis: System Mass (kg) ranging from 0 to 7000
  - X-axis: Duration (days) ranging from 0 to 200

Lines indicating the trend of system mass over duration for different optimization periods.