RESOLVE 2010 Field Test

International Lunar Surface Operations • In-Situ Resource Utilization Analog Test

Big Island, Mauna Kea

2010
RESOLVE

- EBRC – drill and crusher (CSA/Norcat)
- RVC – reactor and gas analysis (GRC and KSC)
- LWRD – fluid system, water and hydrogen capture (KSC)
- ROE – oxygen production (hydrogen reduction), not performed in 2010 Field Test (JSC)
- Mobility
  - SRCan (2010)
EBRC
Excavation and Bulk Regolith Characterization

- Drill, Crusher, Metering Sample Delivery
  - Capable of 1 meter depth
  - Captures soil core and inserts sample into crusher to crush soil to <1 mm size particles
  - Crusher also weighs sample and delivers 20 grams at a time into the reactor
RVC
Regolith Volatiles Characterization

Reactor – heated 80 gram sample
auger/core heater design
performed both RVC and ROE
Gas Chromatograph – analyzed volatiles
MEMS technology
LWRD
Lunar Water Resources Demonstration

- Fluid system
  - Backup measurement of water and hydrogen
  - Capture/release water and hydrogen
RESOLVE fluid subsystems

GC – systems 6.8Kg
Hydrogen Reduction systems 7Kg
Water Capture systems 22.2Kg
Frame & mounting hardware 4Kg
Reactor 18.1Kg
Total 58.1Kg
2008 Field Test

- Integration onto Scarab Rover (CMU) with GSE cart for power, electronics, vacuum pump, gas commodities
- Local command/control
- Volatile characterization with water doping
- Oxygen production
- First field test of integrated system
2010 Field Test Goals

- **Scientific goal**
  - demonstrate evolution of low levels of hydrogen and water as a function of temperature

- **Engineering goals**
  - Integration onto new rover (CSA)
  - Miniaturization of electronics rack
  - Operation from battery packs (elimination of generator)
  - Remote command/control
  - Operation while roving
2008
Scarab rover and GSE cart with generator

2010
Juno tandem rover
Drill Site 2
Crater Rim

Drill Site 3
Crater Basin
RESOLVE FIELD TEAM
Remote Command/Control from KSC

- LabView webservice published to internet
- Satellite connection → ExDOC (CSA) → KSC
- Streaming video for situational awareness
Current GC System

• Current weight
  – GC – 4.5 kg
  – Neon carrier gas - 2.2 kg
  – Valves - 1.8kg (2 Valco selector valves)
• Current time for analysis (3-4 minutes with valve purge)
• Analyze samples up to 150C
• Analytes tested for last field test
  – N₂, O₂/Ar, H₂, He, CH₄, CO, CO₂, water (H₂S and NH₃ tested for previous field test)
• Challenges
  – Water calibration at wide range
  – Limit of detection for water
  – Unknown components can be difficult to identify
  – GC required its own laptop computer to talk to Labview
  – Require 2-7psid to sample (prevented sampling from ST)
Operational Procedure

- Drill
- Crush
- Deliver tephra to reactor
- Add dosed tephra and metal hydride to reactor
- Purge reactor with Argon (inert atmosphere for hydrogen release)
- Seal reactor and heat to 150°C, recording GC measurements every 3-4 minutes
- Cool reactor
- Dump analyzed tephra
Water Doping

- Residual absorbed water on dried tephra (water contained ~1% by weight)
- Various amounts of liquid water was added to tephra
- Wet tephra was added to reactor after crushed sample was delivered

Hydrogen Doping

- Metal hydride (Hy-Stor 207) used as a hydrogen source
- Metal hydride made and passivated on site
- Metal hydride added to reactor after crushed sample was delivered
Gas evolution in Reactor

- Argon was used as purge gas
- Hydrogen, water, carbon dioxide were evolved during the run
Table 1 Sample composition of field samples (Feb) and lab samples (Jan) during integrated testing

<table>
<thead>
<tr>
<th>Date</th>
<th>g tephra</th>
<th>g MH</th>
<th>mL water added</th>
<th>total g</th>
<th>% water</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-Feb</td>
<td>72.0</td>
<td>10.0</td>
<td>0.3</td>
<td>82.3</td>
<td>0.4</td>
</tr>
<tr>
<td>4-Feb</td>
<td>75.0</td>
<td>5.0</td>
<td>0.1</td>
<td>80.1</td>
<td>0.1</td>
</tr>
<tr>
<td>5-Feb</td>
<td>&gt;12.6 ads only</td>
<td></td>
<td></td>
<td>73.5</td>
<td></td>
</tr>
<tr>
<td>5-Feb</td>
<td>55.0</td>
<td>19.4</td>
<td>0.5</td>
<td>74.9</td>
<td>0.7</td>
</tr>
<tr>
<td>5-Jan</td>
<td>83.3</td>
<td>3.08</td>
<td>0.25</td>
<td>86.63</td>
<td>0.3</td>
</tr>
<tr>
<td>12-Jan A</td>
<td>80.23</td>
<td>4.08</td>
<td>0.2</td>
<td>84.51</td>
<td>0.2</td>
</tr>
<tr>
<td>12-Jan B total</td>
<td>80.28</td>
<td>3.15</td>
<td>0.5</td>
<td>83.93</td>
<td>0.6</td>
</tr>
</tbody>
</table>
Wt Percent H\(_2\), H\(_2\)O and CO\(_2\) generated

<table>
<thead>
<tr>
<th>Date</th>
<th>g H(_2)</th>
<th>g H(_2)O</th>
<th>g CO(_2)</th>
<th>H(_2) wt %</th>
<th>H(_2)O wt %</th>
<th>CO(_2) wt %</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-Feb</td>
<td>0.00369</td>
<td>0.03710</td>
<td>0.01959</td>
<td>0.00448</td>
<td>0.04508</td>
<td>0.02381</td>
</tr>
<tr>
<td>4-Feb</td>
<td>0.00005</td>
<td>0.02486</td>
<td>0.00392</td>
<td>0.00006</td>
<td>0.03104</td>
<td>0.00490</td>
</tr>
<tr>
<td>5-Feb</td>
<td>0.00235</td>
<td>0.02215</td>
<td>0.01258</td>
<td>0.00319</td>
<td>0.03014</td>
<td>0.01711</td>
</tr>
<tr>
<td>5-Feb</td>
<td>0.00380</td>
<td>0.01938</td>
<td>0.00825</td>
<td>0.00507</td>
<td>0.02587</td>
<td>0.01101</td>
</tr>
<tr>
<td>5-Jan</td>
<td>0.00024</td>
<td>0.02358</td>
<td>0.00870</td>
<td>0.00028</td>
<td>0.02722</td>
<td>0.01004</td>
</tr>
<tr>
<td>12-Jan A</td>
<td>0.01011</td>
<td>0.01261</td>
<td>0.00582</td>
<td>0.01197</td>
<td>0.01493</td>
<td>0.00689</td>
</tr>
<tr>
<td>12-Jan B 1st xfer</td>
<td>0.00766</td>
<td>0.05324</td>
<td>0.01378</td>
<td>0.00913</td>
<td>0.06343</td>
<td>0.01642</td>
</tr>
<tr>
<td>12-Jan B 2nd xfer</td>
<td>0.00544</td>
<td>0.04528</td>
<td>0.02769</td>
<td>0.00648</td>
<td>0.05396</td>
<td>0.03299</td>
</tr>
<tr>
<td>12-Jan B total</td>
<td>0.00842</td>
<td>0.06599</td>
<td>0.03305</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 2* GC analysis of evolved gases in the reactor during heating of reactor to 150C
Hydrogen, water, carbon dioxide and argon were measured in the reactor. Argon was used as the purge gas prior to heating the sample. Data is from the last GC sample prior to transfer with the amount of each species calculated based on the GC data, temperature, volume, and temperature of the reactor.

<table>
<thead>
<tr>
<th>Date</th>
<th>Field</th>
<th>Test</th>
<th>Data</th>
<th>Lab</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-Feb</td>
<td>0.000369</td>
<td>0.03710</td>
<td>0.01959</td>
<td>0.0045</td>
</tr>
<tr>
<td>4-Feb</td>
<td>0.00005</td>
<td>0.02486</td>
<td>0.00392</td>
<td>0.0001</td>
</tr>
<tr>
<td>5-Feb</td>
<td>0.00235</td>
<td>0.02215</td>
<td>0.01258</td>
<td>0.0032</td>
</tr>
<tr>
<td>5-Feb</td>
<td>0.00380</td>
<td>0.01938</td>
<td>0.00825</td>
<td>0.0051</td>
</tr>
<tr>
<td>5-Jan</td>
<td>0.00024</td>
<td>0.02358</td>
<td>0.00870</td>
<td>0.0003</td>
</tr>
<tr>
<td>12-Jan A</td>
<td>0.01011</td>
<td>0.01261</td>
<td>0.00582</td>
<td>0.0120</td>
</tr>
<tr>
<td>12-Jan B(1)</td>
<td>0.00766</td>
<td>0.05324</td>
<td>0.01378</td>
<td>0.0091</td>
</tr>
<tr>
<td>12-Jan B(2)</td>
<td>0.00544</td>
<td>0.04528</td>
<td>0.02769</td>
<td>0.0065</td>
</tr>
<tr>
<td>12-Jan B total</td>
<td>0.00842</td>
<td>0.06599</td>
<td>0.03305</td>
<td>0.0065</td>
</tr>
</tbody>
</table>
Water and hydrogen were generated during the transfer of the gas to the surge tank, quantifying excess will require sampling the surge tank after transfer.

<table>
<thead>
<tr>
<th>Field</th>
<th>Date</th>
<th>GC water in reactor (g)</th>
<th>GC data xfer water (g) using H2/H2O ratio</th>
<th>Capacitance Water (g)</th>
<th>% difference Cap vs GC calc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test</td>
<td>Feb 3 2010</td>
<td>0.0371</td>
<td>0.0616</td>
<td>0.0186</td>
<td>-69.9</td>
</tr>
<tr>
<td>Test</td>
<td>Feb 4 2010</td>
<td>0.0249</td>
<td>0.0487</td>
<td>0.0100</td>
<td>-79.5</td>
</tr>
<tr>
<td>Data</td>
<td>Feb 5 2010 run 1</td>
<td>0.0222</td>
<td>0.0229</td>
<td>0.0513</td>
<td>124.4</td>
</tr>
<tr>
<td>Data</td>
<td>Feb 5 2010 run 2</td>
<td>0.0194</td>
<td>0.0205</td>
<td>0.0006</td>
<td>-97.1</td>
</tr>
<tr>
<td>Lab</td>
<td>Jan 5 2010</td>
<td>0.0236</td>
<td>0.0431</td>
<td>-0.0075</td>
<td>-117.4</td>
</tr>
<tr>
<td>Data</td>
<td>Jan 12 2010 run 1</td>
<td>0.0126</td>
<td>0.0120</td>
<td>0.0082</td>
<td>-31.6</td>
</tr>
<tr>
<td>Data</td>
<td>Jan 12 2010 run 2</td>
<td>0.0660</td>
<td>0.1434</td>
<td>0.1791</td>
<td>24.9</td>
</tr>
</tbody>
</table>

The capacitance beds used for this field test were larger than the previous system, the amount of water transferred was below the detection limit of the system (shown by standard deviations). Repeated heating and cooling of the beds also caused water migration and affected results.
Capacitance Water Capture Beds

- Bed capacity was designed for hydrogen reduction.
- Water transferred during RVC ops were much too low to quantitate using these capacitance beds.
- Change in size or geometry can increase sensitivity of this technique.

Water (g) vs Voltage output of Capacitance Bed Measurement

- Bed 1 Calibration

[Graph showing the relationship between Water (g) and Bed 1 Output (v)]
Future Direction

- **GC-MS**
  - Additional capability to identify unknowns
  - Increased accuracy of MS compared to standalone analysis
  - Ability to detect isotopes of interest

- **Additional Instrumentation**
  - Neutron spectrometer

- **Fluid system**
  - Manifold design with smaller valves
  - Complete integration of recirculation loops for volatile analysis and oxygen production

- **Electronics**
  - Miniturization and move towards space rated platform