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Produced by the NASA Center for Aerospace Information (CASI)
Lunar Water Resource Demonstration (LWRD) Test Results

ex luna, aqua
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Outline

• Background
• RESOLVE Project and Field Demonstration
• LWRD Design Review
  - Fluid systems design
  - Water Bed design
  - Other component design
  - ProE 3-D model
  - Hydrogen bed calculations
  - Actual components
• Testing Plan
• Lab and Field Demonstration Results
• Hydrogen Capture/Quantification Test Results
• Summary
Background

- LWRD is part of RESOLVE (Regolith and Environment Science & Oxygen and Lunar Volatile Extraction)
- RESOLVE is an ISRU ground demonstration:
  - A robotic rover to explore a permanently shadowed crater at the south or north pole of the Moon
  - Drill core samples down to 1 meter
  - Heat the core samples to 150°C
  - Analyze gases and capture water and/or hydrogen evolved
  - Use hydrogen reduction to extract oxygen from regolith
- The field demo took place on Mauna Kea as an analog site for the Moon
- JSC, GRC, KSC, NORCAT, CSA and CMU involved
- The same technology is applicable to Mars
RESOLVE Block Diagram

CMU
Scarab Rover
- Mobility
- Structural Support
- Stable Platform

NORCAT (CA)
Drill
- Core Samples
- Sample Delivery
- Quarter Cores

NORCAT (CA)
Crusher
- Crush Samples
- Weigh
- Sample to Reactor

GRC
Reactor
- Heat Samples
- 150C for RVC/LWRD
- 900C for ROE

KSC
RVC
- GC Analysis
- Quantify Water, H₂ and Other Gases

KSC
LWRD
- Capture/Quantify Water
- Purify Gas for H₂
- Capture/Quantification

JSC/KSC
GSE Cart
- Power
- Electronics
- Argon and Compressed Air
- Vacuum Pump

JSC/KSC
ROE
- Oxygen Extraction
- Produce and Quantify Water

KSC Software – Control and Operate Chemistry Systems; Collect Data

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RESOLVE/Scarab Rover

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Nov. 2008 ISRU Field Test Infrastructure and Test Layout

Slide by Jerry Sanders and Bill Larson
Lunar-Like Terrain on Mauna Kea
Purpose of LWRD

- Capture up to 6 g of water per regolith/soil core sample and quantify up to 20 g of water (backup to GC measurements)
- Capture and quantify up to 0.10 g of hydrogen from same core sample (backup to GC measurements)
- Quantify within 20% accuracy
Design Review

- Prevent water condensation
  - Operate in 150C/130C Hot Boxes
  - Heated head recirculation pump
  - Heat trace Reactor gas lines
- Minimize number of transfers
  - 500 cc Surge Tank
- Absorb water at 130C
  - "Moisture Gone" zeolite absorbent
- Have sufficient water absorption capacity
- Quantify water
  - Desorption of MG is too slow; use RH probe, P, V, and T
Design Review (Cont.)

- Absorb/desorb hydrogen efficiently
  - FSEC developed new hydride former; works at room temp.
- Operate during 8-12 hr workday
  - Desorb water beds overnight (or during ROE)
  - Split full RESOLVE ops over two days
- Stay under 60 kg mass limit
  - Minimized masses of individual components
  - Transferred Ar, vacuum pump and electronics to GSE
- Demonstration on Mauna Kea in November 2008
  - Keep close track of schedule; fix issues quickly
- Limited budget
  - Work efficiently; minimize equipment costs
LWRD Process Summary

- At 150C in the Reactor, transfer gases to Surge Tank; measure RH, P, & T; and transfer to Water Beds two times (up to ~1.5 g water)
- Transfer residual gases to Hydrogen Bed, vent unabsorbed gases, heat to 300C and measure P & T of desorbed gas in Surge Tank and H₂ Bed (skipped this step in Hawaii demo)
- Subsequent transfers: measure RH, P, & T in Surge Tank since gases will consist of >90% water vapor; and vent
- Repeat sequence for each quarter core
Water Beds

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LWRD Surge Tank

Volume ≈ 500 cc
(w/ RH probe)
Recirculation Pump

Pump heads withstand up to 170C

Design goals:
- Minimum inlet vacuum
- Maximum outlet pressure
- Minimum mass and power
High Temperature Latching Solenoid Valves

Modified standard solenoid valves at KSC
Hydrogen Desorption

- $H_2$ Bed size = 50 g of new absorber
- Absorber $H_2$ capacity = 0.10 g (0.2%)
- Average lunar $H_2$ expected = 0.088 g per ¼ core (0.11% $H_2$) if all elemental hydrogen
- Free bed volume = 25.3 cc
- $\Delta P$ at 300C = 1200 psi (rated at 150 psi) minus equilibrium as with water bed desorption
- Therefore, use Surge Tank; $\Delta P$ = 32 psi
- Encourages dehydriding to completion
Partially Assembled LWRD
Water Beds Added
Mounted in SCARAB Rover
Testing at CMU
Field Test Plan

- Lab – full capabilities demonstration
- Hawaii – no hydrogen absorption/desorption/quantification demonstration (run in lab at KSC after Field Demo)
Field Demo Site on Mauna Kea
Eating Mauna Kea’s Dust
GSE Cart and Rover Ready to Operate
Drilling for Analog Lunar/Martian Water
## Lab/Field Demonstration Results

<table>
<thead>
<tr>
<th>Date</th>
<th>Total Water Transferred</th>
<th>Mass of Tephra</th>
<th>% Water</th>
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</thead>
<tbody>
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<td>9/24/08</td>
<td>0.27g</td>
<td>85g</td>
<td>0.31</td>
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<tr>
<td>9/24/08</td>
<td>0.08g</td>
<td>90g</td>
<td>0.09</td>
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<td>85g</td>
<td>0.41</td>
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<td>85g</td>
<td>0.39</td>
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<tr>
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<td>11/4/08</td>
<td>0.11g</td>
<td>66g</td>
<td>0.17</td>
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<tr>
<td>11/5/08</td>
<td>0.13g</td>
<td>72g</td>
<td>0.18</td>
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<tr>
<td>11/6/08</td>
<td>0.16g</td>
<td>92g</td>
<td>0.17</td>
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<tr>
<td>11/8/08</td>
<td>0.13g</td>
<td>71g</td>
<td>0.19</td>
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<td>0.11g</td>
<td>76g</td>
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<tr>
<td>11/10/08</td>
<td>0.19g</td>
<td>90g (LN₂)</td>
<td>0.22*</td>
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</table>
## Field Demonstration Results

<table>
<thead>
<tr>
<th>Date</th>
<th>RVC GC results (corrected)</th>
<th>LWRD results (corrected)</th>
<th>% difference</th>
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</thead>
<tbody>
<tr>
<td>11/5/08</td>
<td>48mg</td>
<td>39mg</td>
<td>-18%</td>
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<tr>
<td>11/6/08</td>
<td>47mg</td>
<td>57mg</td>
<td>21%</td>
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<td>46mg</td>
<td>47mg</td>
<td>3%</td>
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<tr>
<td>11/9/08</td>
<td>45mg</td>
<td>34mg</td>
<td>-24%</td>
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<tr>
<td>11/10/08</td>
<td>52mg</td>
<td>65mg</td>
<td>24%</td>
</tr>
</tbody>
</table>

Average difference: 18%
Pure $H_2$ Absorption

$H_2$ Bed Temperature, °C

Surge Tank Pressure, psia

$H_2$ Bed Capacity = 0.055g

$H_2$ Bed Pressure, psia

Time, min

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Hydrogen Absorption and Desorption by LWRD

~91% Absorption

~73% Recovery

Hydrogen in Surge Tank, mg

Hydrogen, mg

y = 0.909x - 0.430

R² = 0.978

y = 0.733x

R² = 0.957

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Summary

• LWRD Team has accomplished all major goals in design, construction, and testing
• Successfully completed November field demo on Mauna Kea in Hawaii
• Achieved acceptable agreement with GC results for water and hydrogen as a backup system
• Returning to Mauna Kea in February 2010 for further testing with CSA