RESOLVE MISSION ARCHITECTURE FOR LUNAR RESOURCE PROSPECTING AND UTILIZATION.

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Introduction: Design Reference Mission (DRM) evaluations were performed for the The Regolith & Environment Science, and Oxygen & Lunar Volatile Extraction (RESOLVE) project to determine future flight mission feasibility and understand potential mission environment impacts on hardware requirements, science/resource assessment objectives, and mission planning. DRM version 2.2 (DRM 2.2) is presented for a notional flight of the RESOLVE payload for lunar resource groundtruth and utilization (Figure 1) [1]. The rover/payload deploys on a 10 day surface mission to the Cabeus crater near the lunar south pole in May of 2016. A drill, four primary science instruments, and a high temperature chemical reactor will acquire and characterize water and other volatiles in the near subsurface, and perform demonstrations of In-Situ Resource Utilization (ISRU). DRM 2.2 is a reference point, and will be periodically revised to accommodate and incorporate changes to project approach or implementation, and to explore mission alternatives such as landing site or opportunity.

RESOLVE Project and Payload: The Regolith & Environment Science, and Oxygen & Lunar Volatile Extraction (RESOLVE) project is developing the capability to explore and utilize the Moon's polar region volatiles in the 2015-2016 timeframe [2, 3]. The project is currently developing a third generation Ground Development Unit for field testing at Mauna Kea, Hawaii in the summer of 2012.

The estimated RESOLVE flight payload is 72 kg with margin. Major elements include the:

- Drill capable of acquiring core samples to 1 m depth, or augered cuttings to 0.5 m depth.
- ISRU Reactor capable of heating samples to 150 C for volatile extraction, or 900 C for oxygen extraction and water production via hydrogen reduction processing.
- Gas Chromatograph and Mass Spectrometer used to assay volatiles driven off by the reactor.
- Neutron Spectrometer used to detect subsurface hydrogen during 3,000 m total rover traverses.
- Near Infrared Spectrometer used to detect surface volatiles during rover traverses, as well as analyze auger cuttings.

FIGURE 1: RESOLVE DRM 2.2 SUMMARY

Destination:	**Moon South Pole**
Landing Site:	**Cabeus A1**
Latitude	85.75 S
Longitude	45 W
Surface Duration:	**10 days** (8 w/ sun)
Surface Dates:	**5/19-5/29/2016** (10 day)
2016 Secondary	6/18-6/25/2016 (7.5day)
2015 Primary	5/6 - 5/13/2015 (7 day)
2015 Secondary	5/31-6/10/2015(10.5day)
Primary Spacecraft:	**Rover**
Power Strategy:	**Solar PV + Battery**
Solar Array	250 We
Secondary Battery	3500 W-hr
Comm. Strategy:	**Direct-To-Earth** McMurdo+Troll
Survey Track:	**3,000 m** cumulative
Payload:	
Drill	5 x 1 m core 10 x 0.5 m auger
ISRU Reactor	25 Samples @ 150 C 4 ISRU Demos @ 900 C
GasChrom./MassSpec.	25 Samples
Neutron Spectrometer	3,000 m
Near-IR Spectrometer	3,000 m, 10 auger cuttings
Mission Energy:	**51,500 W-hr** available
Mission Ave. Power:	**181 W** predicted
Payload Mass:	**72 kg**
Rover+P/L Mass:	**243 kg**
Landed Mass:	**1,285 kg**
Wet Mass @ TLI:	**3,476 kg**
Launch Vehicle:	**Atlas V 411**

Comparative Architectures: A number of alternative implementation architectures were first considered, characterized by the primary "active" surface spacecraft, and the number and nature of sites visited. Major options included a:

- Lander to one stationary site.
- "Hopper" Lander to multiple stationary sites.
- Rovers powered by Batteries, Solar Arrays, Solar Array and Battery, or Radioisotopes.
- Active Lander & Rover with split payload.

The architectures were qualitatively assessed for Location, Science Return, Cost and Risk. The Solar+Battery Rover ("Sun & Shade" scenario) was selected for further study due to its ability to survive a several day mission, range 1000's of meters beyond the landing site, sortie into shadowed areas, be developed for reasonable cost, and possessing the lowest aggregate program and science risk. A highly cost constrained scenario might consider sacrificing the rover and surface mobility for a reusable "Hopper" type lander. "Splitting" the payload across a small lander and rover would have promise for a lunar X-Prize scenario.

Spacecraft: The DRM 2.2 surface mission is implemented by a 243 kg gross rover/payload capable of surveying 3,000 m about the landing site. Power is provided by a 250 We solar array and 3,500 W-hr rechargeable battery. The 10 day mission is predicted to consume 181 We on average, and 43 kW-hr out of an available 51 kW-hr. Communication occurs Direct-to-Earth to Antarctic ground stations at McMurdo and Troll. The "wet" lander/rover/payload stack has a mass of 3,476 kg after trans-lunar injection. An Atlas V 411 or similar launch vehicle is required.

Landing Sites: Various south and north pole landing sites were assessed and screened for:

- Volatiles indicated in the near subsurface.
- Sunlight availability to power solar arrays.
- Communications availability direct-to-earth.
- Terrain of traversable slope and roughness.

The selected reference site for DRM 2.2 is Cabeus A1 (85.75 deg S, 45 deg W) near the lunar south pole. The location allows direct groundtruth and calibration of LCROSS results [4], and affords a 10 day surface mission with continuous line-of-sight communication to Earth, and at least 8 days of cumulative sunlight.

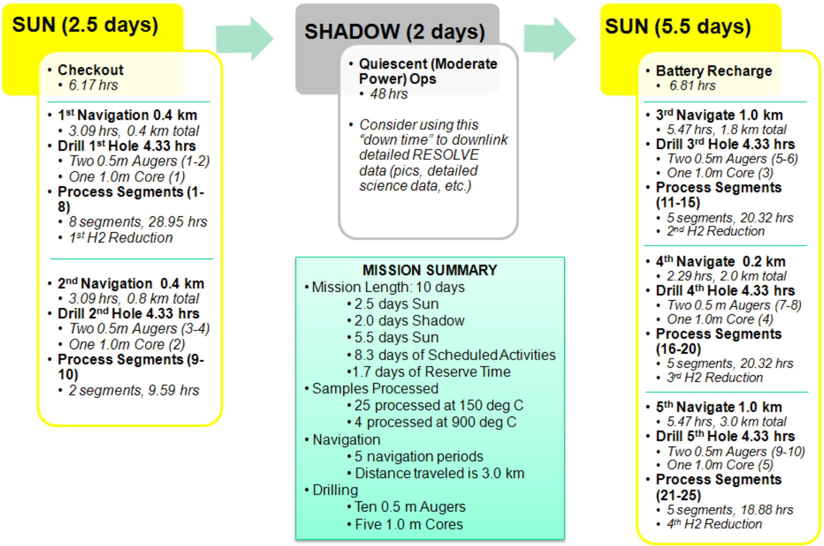
Opportunities with Both Communications and Sunlight: Mission opportunities with at least 7 days of coincident communications and sunlight were investigated for various sites, poles, months, and for the years 2015 and 2016. South Pole primary opportunities occur in May, with secondary attempts possible in June. For DRM 2.2, specific surface mission dates and durations are found in Figure 1. The North Pole appears more flexible, with opportunities ranging from October to March, depending upon site.

Operations Concept and Analysis: The DRM 2.2 Operations Concept is summarized in Figure 2, with cumulative science noted in Figure 1. An initial 2.5 days of sunlit operation allows deployment and checkout, and two cycles of roving, surveying, drilling and processing. The next two days assume a low-power quiescent period to accommodate a transient shadow. The remaining 5.5 days allow three additional cycles.

Team and Methodology: The RESOLVE Mission Architecture Team consists of the authors and colleagues at NASA JSC, KSC, ARC and GSFC. Members represent the range of necessary disciplines and perspectives including science, engineering, design, analysis, operations, subsystems and stakeholder/management. The team meets weekly in a distributed manner using telecon and WebEx. Sessions are scheduled to address informational presentations, problem/issue resolution, or Collaborative Design sessions.

References: [1] George J. A. et.al. (2011) *RESOLVE "Sun & Shadow" DRM 2.2 Mission Architecture Data Book*. [2] Sanders G. B. et.al. (2005) *International Lunar Conference*. [3] Larson W. E. (2011) *62nd Internat. Astronautical Conference*, IAC-11-A5.1.4. [4] Colaprete A. et.al (2010) *Science Vol. 330 no. 6003 pp. 463-468*.

FIGURE 2: "SUN & SHADOW" OPERATIONS CONCEPT



SUN (2.5 days)

- **Checkout**
  - *6.17 hrs*
- **1st Navigation 0.4 km**
  - *3.09 hrs, 0.4 km total*
- **Drill 1st Hole 4.33 hrs**
  - *Two 0.5m Augers (1-2)*
  - *One 1.0m Core (1)*
- **Process Segments (1-8)**
  - *8 segments, 28.95 hrs*
  - *1st H2 Reduction*
- **2nd Navigation 0.4 km**
  - *3.09 hrs, 0.8 km total*
- **Drill 2nd Hole 4.33 hrs**
  - *Two 0.5m Augers (3-4)*
  - *One 1.0m Core (2)*
- **Process Segments (9-10)**
  - *2 segments, 9.59 hrs*

SHADOW (2 days)

- **Quiescent (Moderate Power) Ops**
  - *48 hrs*
- *Consider using this "down time" to downlink detailed RESOLVE data (pics, detailed science data, etc.)*

MISSION SUMMARY

- Mission Length: 10 days
  - 2.5 days Sun
  - 2.0 days Shadow
  - 5.5 days Sun
  - 8.3 days of Scheduled Activities
  - 1.7 days of Reserve Time
- Samples Processed
  - 25 processed at 150 deg C
  - 4 processed at 900 deg C
- Navigation
  - 5 navigation periods
  - Distance traveled is 3.0 km
- Drilling
  - Ten 0.5 m Augers
  - Five 1.0 m Cores

SUN (5.5 days)

- **Battery Recharge**
  - *6.81 hrs*
- **3rd Navigate 1.0 km**
  - *5.47 hrs, 1.8 km total*
- **Drill 3rd Hole 4.33 hrs**
  - *Two 0.5m Augers (5-6)*
  - *One 1.0m Core (3)*
- **Process Segments (11-15)**
  - *5 segments, 20.32 hrs*
  - *2nd H2 Reduction*
- **4th Navigate 0.2 km**
  - *2.29 hrs, 2.0 km total*
- **Drill 4th Hole 4.33 hrs**
  - *Two 0.5 m Augers (7-8)*
  - *One 1.0m Core (4)*
- **Process Segments (16-20)**
  - *5 segments, 20.32 hrs*
  - *3rd H2 Reduction*
- **5th Navigate 1.0 km**
  - *5.47 hrs, 3.0 km total*
- **Drill 5th Hole 4.33 hrs**
  - *Two 0.5m Augers (9-10)*
  - *One 1.0m Core (5)*
- **Process Segments (21-25)**
  - *5 segments, 18.88 hrs*
  - *4th H2 Reduction*