# Lunar Knowledge Requirements for Human Exploration

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# Overview

- Background
  - Context for the workshop is President Bush's space exploration plan
  - Workshop planning, organization, and goals
- Major findings of the workshop
  - Identify and characterize resources
  - Permit safe landing
  - Select landing site
  - Moon as a test bed for exploration of Mars & other sites
  - R&D program
- Usefulness of in-situ resources for long duration exploration
- Strategy for a series of missions

# Steering Committee

Ben Bussey, Applied Physics Laboratory
Michael Duke, Colorado School of Mines
Paul Lucey, University of Hawai`i
Stephen Mackwell, Lunar and Planetary Institute
Gordon McKay, Johnson Space Center
Marc Norman, Australian National University
Mark Robinson, Northwestern University
Charles Shearer, University of New Mexico
G. Jeffrey Taylor, University of Hawai`i

## Activities and Schedule

- Preliminary planning, January 2004, beginning two days after President Bush's announcement
- Steering committee teleconference on February xx, 2004
- Draft agenda sent to potential participants February xx, 2004
- Meeting held March 1–2, 2004
- Results not intended to be community consensus given the short timescale, but to be based on broad input and to provide science and resource exploration direction that can be useful in current planning activities.

**Participants in the March 1–2 Workshop on Lunar Knowledge Requirements for Human Exploration**

Bruce Banerdt
Nancy Ann Budden
Ben Bussey
Bryan Butler
Bruce Campbell
Dave Carrier
John Connolly
Dana Crider
Dave Criswell
Ramon De Paula
Dale Dubbert
Mike Duke
Rick Elphic
Lisa Gaddis
Jeff Gillis
Steve Hawley
Martin Houghton
Chris Lichtenberg
Terri Lomax
Paul Lucey
David McKay
Gordon McKay
Ed McCullough
Steve Mackwell
Wendell Mendell
Clive Neal
Marc Norman
Stewart Nozette
Mike O'Neal
Jim Papike
Leah Pate
Tom Prettyman
Kurt Retherford
Wayne Richie
Gunter Riegler
Mark Robinson
Cris Romig
Chip Shearer
Paul Spudis
David Smith
George Tahu
Jeff Taylor
Larry Taylor
David Vaniman
Rich Vondrak
Brenda Ward
John Young

# Context for the Workshop

- President Bush announced a new vision for the U.S. space exploration program:
- "Undertake lunar exploration activities to enable sustained human and robotic exploration of Mars and more distant destinations in the solar system"
  - For Mars, the plan notes: "Conduct human expeditions to Mars after acquiring adequate knowledge about the planet using robotic missions and *after successfully demonstrating sustained human exploration missions to the Moon"*
  - "Sustained" implies use of *in situ* resources (ISRU), development of extensive infrastructure, and astronaut stays for long times

# Context (continued)

- "Starting no later than 2008, initiate a series of robotic missions to the Moon to prepare for and support future human exploration activities"
  - This was a central part of this workshop
  - Emphasis is on planning for human return
  - Workshop discussions fed into deliberations by the Objectives/Requirements Definition Team (ORDT) defining the 2008 orbital mission

# Context (continued)

- "Conduct the first extended human expedition to the lunar surface as early as 2015, but no later than the year 2020"
  - Must plan human activities before 2015-2020
  - What will they do, besides maintain their base?
    - Field studies; experiments using rovers
    - Other science (e.g., astronomy, life science)
    - Resource utilization experiments
  - There was not enough time to address human activities at this workshop

# Context (continued)

- "Use lunar exploration activities to further science, and to develop and test new approaches, technologies, and systems, including use of lunar and other space resources, to support sustained human space exploration to Mars and other destinations"
  - Science is an important part of this effort (A commission was set up to, among other things, "examine…a science research agenda to be conducted on the Moon"
  - Resource exploration and utilization central to it
  - "Sustained" implies that ISRU is essential

# Workshop Goals

- Determine what we need to know to make human missions to the Moon effective in advancing the goal of human exploration of solar system
- "Effective" means:
  - Develop the capability to live and work on another planetary body
  - Develop methods to explore for and use lunar resources
  - Conduct technology and ISRU experiments
  - Demonstrate capabilities by doing substantive scientific research
  - Gather data needed before humans return to the Moon
- Provide information to ORDT meeting that followed the workshop

# Workshop Objectives

- Review current data sets
- Determine what future measurements are needed
  - Resource assessment
  - Surface geotechnical properties
  - Geographic properties (topography, geodetic control, location of permanently shadowed areas in polar regions, etc.)
- Determine quality and priority of measurements needed
  - Precision, accuracy, spatial resolution
  - Order in which data should be collected
- Establish priorities for data collection

# Working Groups

- Mission Operations (Ben Bussey, Chair)
- Assessment of Resources (Jeff Taylor, Chair)
- Resource and Regolith Processing (Larry Taylor, Mike Duke, Chairs)
- Goals of the subgroups:
  - Identify information lacking
  - Suggest investigations/measurements that need to be done—emphasis is on the measurements, not on how to make them
  - Determine requirements of those measurements (precision, spatial resolution, etc.)
  - Prioritorize the investigations and measurements
  - Draft sub-group reports (powerpoint)
  - Audience for report: Codes S, T, U, M, and others involved in implementing the program

# Resources

- Identify & Characterize lunar resources
  - Polar volatiles (is there $H_2O$?)
  - Polar environment
  - Pyroclastic deposits
  - Non polar regoliths (e.g. ilmenite)
- Demonstrate techniques to extract & utilize in-situ resources

# Permit Safe Surface Operations

- Safe Landing & Operations
  - High resolution characterization of surface topography and boulder location
  - Nature of the regolith
  - Improved geodetic control & gravity
- Long duration physiology
  - Radiation environment
  - Radiation effects
  - Dust effects

# Landing Site Selection

- Landing site selection dependent on mission goal
- Ability to choose optimal site
  - 15 m/pixel resolution mineralogic characterization
  - Analyze small crater ejecta that samples below the regolith
  - Example: spectrometer covering from 380-2800 nm @ 5 nm
  - 3D Regolith properties
    - block distribution
    - substrate roughness
    - Regolith thickness
  - Polar lighting conditions (eclipse durations)
  - Image coverage of permanently shadowed region

# Commonality Between Moon and Mars

- Potential for lunar methane production
  - Enough carbon/hydrogen in lunar regolith to produce methane
  - Methane is an obvious propellant product on Mars, using atmospheric $CO_2$ and hydrogen from Earth or Mars
- Gas separation technologies similar
- Extraction of water on Mars from regolith is similar to extraction of volatiles from lunar regolith

# Moon as a Test Bed

- *In situ* resource utilization
- Key *in situ* measurement capabilities
  - Drilling
  - Instruments
- Exploration infrastructure
  - Sample handling
  - Mission operations experience
  - Autonomous data analysis
  - Long duration power generation
  - Engineering tests
  - Remote operations
  - Human-robotic partnerships
- Flight opportunity for Mars instruments

# Strategic Needs

- In-situ robotic demonstration of resource extraction technology for non-polar regions
  - Oxygen extraction from basaltic regolith/pyroclastic glass
    - Closed cycle production of oxygen
  - Hydrogen extraction demonstration
    - In-situ abundances of extractable hydrogen
    - Extraction, separation, purification processes
  - Regolith excavation and handling

# Strategic Needs

- Exploration of lunar cold traps
- Regolith geotechnical properties in polar environments
  - Soil mechanics properties
  - Tribology of regolith materials
  - Effects on hard surfaces, cutting edges, brushes
  - Electrostatic effects
  - Size distribution, morphology

# Research & Development Program

This workshop has identified an urgent need to develop a significant R&D program to enable effective “robotic missions to the Moon to prepare for and support future human exploration activities”

- *In situ* resource utilization techniques brought to TRL 6-7
  - Need for technology demonstrations (see next slide)
- Instrumentation development to TRL 6-7
- Operations in cold regions (< 100 K)
- Economic and mission risk studies (e.g., risk of use of lunar propellant for human missions)
- Post-mission data analysis program
- Algorithm development
  - e.g. mineral identification and characterization
- Develop the scientific and technical workforce (new generation, attract scientists and engineers from other specialties)

Research & Development Program:

# Technology Development and Demonstrations

- Technology demonstrations, to be combined with ISRU system demonstrations on Earth, then on the Moon and/or in space
  - Cryogenic storage
  - Liquefaction
  - Electrolysis
  - Condensation/gas separation/purification
  - Production scale excavation techniques
  - Dust mitigation
  - Magnetic/electrostatic brushes
  - Microwave applications
  - Systems for deep cold temperatures
  - Doors, valves, airlocks for materials production systems
- Select demonstrations based on expected value of technology for supporting future human exploration activities

The nature of polar volatiles, currently unknown, is a crucial input to the architecture of the exploration program

# Knowledge Needed for Processing (primarily for polar regions)

- Element/constituent/mineral properties
  - Distribution
  - Concentration
  - Low concentration contaminants (e.g. sulfur)
- Volatiles
  - Distribution/concentration and rate of evolution/temperature
  - Loss of various species due to regolith excavation/handling*
- Dust Tribology
  - Shape/size distribution/concentration for wear & filtration
  - Electromagnetic/electrostatic properties*

* Also important for non-polar areas

# Knowledge Needed for Processing (primarily for polar regions)

- Mechanical & Physical properties
  - Shear & bearing strength
  - Compaction-depth distribution
  - Granular cohesion
  - Granular transport properties
  - Bulk density
- Terrain/operation landscape
  - Slopes/gradients
  - Boulder size & distribution in regolith excavation area
  - Amount of pre-screening of large objects required
- Terrestrial Resource Simulants
  - Simulate requirements (chemical/physical)
  - Identify possible source "standards" to distribute to developers

# Orbital Knowledge Requirements

- Radiation impact on human operations
- Characterize the polar environment
  - Spatial concentrations
  - Image of permanently shadowed regions
  - Temperature map
  - Synoptic illumination study
  - Geodetic Model
    - Topography, gravity

# Orbital Knowledge Requirements-2

- High resolution characterization of potential landing sites
  - morphology
  - topography
  - regolith structure
- Resource relevant studies
  - Element maps (including Mg & Al)
  - Mineral identification
  - Magnetic field analyses
  - Atmospheric study
  - Electric field analyses

# Lander Knowledge Requirements

- Highest priority: the presence and abundance of water or hydrogen
  - The outcome affects future lander missions
  - If a useable resource exists then a detailed characterization mission could follow
- Other high priority data
  - Radiation environment
  - Regolith structure
  - Ground truthing of orbital data
- Lower priority measurements
  - Measurements of surface electrical fields
  - Atmospheric characterization

# 2009 Lander

- There was insufficient time to discuss details of the first robotic lander, scheduled tentatively in 2009
- However, there was wide support for a combination ISRU experiment and polar penetrometer mission
  - A lander could deploy one or more penetrators on its way to a non-polar landing site
  - The penetrator(s) would land in places selected on the basis of data from the 2008 orbiter to determine the composition of the volatiles present in the upper meter of the regolith
  - Participants noted that it might be possible to include a penetrator on the 2008 orbiter as well, depending on payload mass and budget