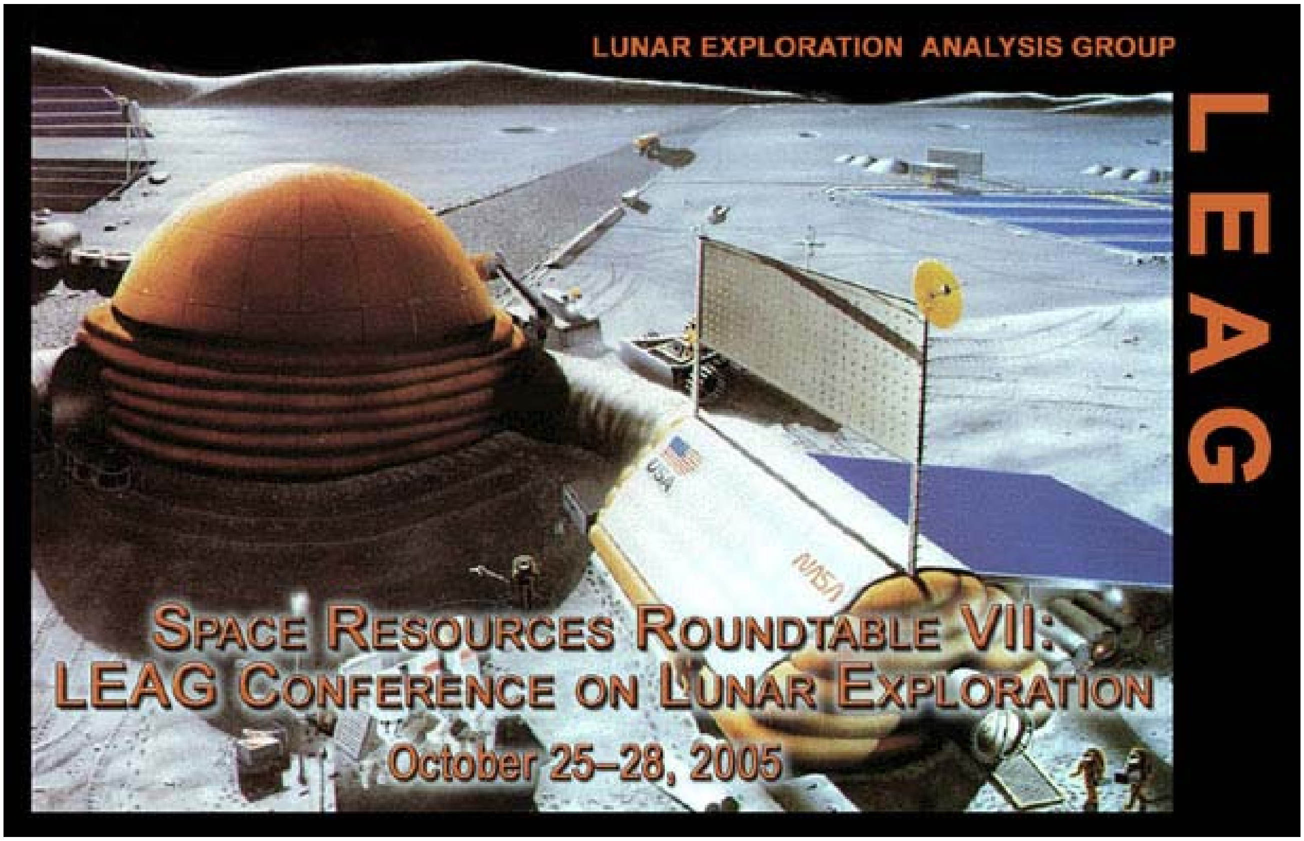

CONFERENCE PROGRAM AND ABSTRACTS

LPI Contribution No. 1287

Space Resources Roundtable VII:
LEAG Conference on Lunar Exploration

October 25–28, 2005
League City, Texas

Sponsored by

Lunar and Planetary Institute
National Aeronautics and Space Administration
Space Resources Roundtable, Inc.
NASA Lunar Exploration Analysis Group

Conveners

G. Jeffrey Taylor, *University of Hawai'i*
Stephen Mackwell, *Lunar and Planetary Institute*
James Garvin, *NASA Chief Scientist*

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PREFACE

This volume contains abstracts that have been accepted for presentation at the Space Resources Roundtable VII: LEAG Conference on Lunar Exploration, October 25–28, 2005, League City, Texas.

Administration and publications support for this meeting were provided by the staff of the Publications and Program Services Department at the Lunar and Planetary Institute.

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THURSDAY, OCTOBER 27, 2005

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(JOINT MEETING WITH LUNAR COMMERCE EXECUTIVE ROUNDTABLE)
8:00 a.m. Marina Plaza Ballroom

8:00–8:15 a.m. Introduction
P. A. Eckert

8:15–8:30 a.m. Synergy of Science, Engineering, and Commerce
R. Tumlinson and G. J. Taylor

8:30–8:45 a.m. Bringing Technology to Market: Developing Sound Business Plans

8:45–9:15 a.m. Lunar Energy Roadmap Discussion
SRR/LEAG Speakers: Technical Issues

9:15–10:00 a.m. Lunar Energy Roadmap Discussion
Executive Speakers: Business Issues

10:00–10:15 a.m. BREAK

10:15–12:15 Breakout Groups
Clarifying Business and Technical Success Factors for Lunar Enabled Enterprises

Marina Plaza Ballroom
Solar Power – Moderator: A. Ignatiev

Hunt Room
Oxygen-Hydrogen Propellant – Moderator: L. A. Taylor

Amphitheater
Multiple-Customer Industrial/Scientific/Exploration Facility – Moderator: H. Benaroya

Poolside
Civil Engineering Enterprises – Moderator: D. Carrier

Oasis Room
Media and Related Products and Services – Moderator: S. Heard

12:15–1:15 p.m. LUNCH – SPEAKER: REX GEVEDEN, *NASA Associate Administrator* Salons A, B and C

PLENARY BREAKOUT GROUP REPORTS AND DISCUSSION
1:15 p.m. Marina Plaza Ballroom

Plenary session in which each of the five panel discussion groups report the essence of their discussions: points of agreement, disagreement, next steps to take, etc.

3:15–3:30 p.m. BREAK

THURSDAY, OCTOBER 27, 2005 (continued)

WHAT NEXT FOR THE SRR AND LEAG?
3:30 p.m. Marina Plaza Ballroom

Moderator: G. J. Taylor

G. M. Cadenhead *

Lunar Entrepreneurs Student Competition **[#2087]** (15-Minutes)

Open discussion of what activities, products, white papers, etc., should be produced by the Space Resources Roundtable and LEAG. There will be time to outline what the products should contain and what the scope of an analysis activity should be. (NOTE: This session is held independently of the Lunar Commerce Executive Roundtable.)

JOINT RECEPTION FOR THE
LUNAR COMMERCE EXECUTIVE ROUNDTABLE AND SRR-LEAG,
AND POSTER SESSION
5:00 p.m. Salons A, B and C

FRIDAY, OCTOBER 28, 2005

FROM THE MOON TO MARS AND BEYOND
8:00 a.m. Marina Plaza Ballroom

Moderator: D. W. Beaty

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Shearer C. K. * [Invited 30-Minutes]
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Lee P. * Braham S. Mungas G. Silver M. Thomas P. West M.
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Beaty D. W. * [Invited]
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Reiter J. W. * Guerrero J. L. Wu D. Wang G. Y.
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Head J. N. * Price C. R. Blair B. R.
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10:00–10:15 a.m. BREAK

Berggren M. * Zubrin R. Rose H. West M. Harber D. Kilgore J. Muscatello A. McNulty M.
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Zubrin R. * Harber D. Snyder G. Kilgore J. Johnson K. Jameson N.
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11:00 a.m.–12:00 p.m. DISCUSSION

12:00 p.m. ADJOURNMENT

Unified Lunar Topographic Model. B. A. Archinal, M. R. Rosiek, R. L. Kirk, and B. L. Redding. U. S. Geological Survey (2255 N. Gemini Drive, Flagstaff, AZ 86001, USA, barchinal@usgs.gov).

Introduction: There are currently two generally accepted lunar horizontal control networks. These are the Unified Lunar Control Network (ULCN) [1] and the Clementine Lunar Control Network (CLCN), both derived by M. Davies and T. Colvin at RAND. Sources of vertical control for the Moon exist as summarized in the Table. These include Clementine lidar [2], polar stereo [3], other stereo [4], radar [5], and Apollo lidar and stereo [6]. Connections between the horizontal and vertical systems exist, but they are only well determined regionally and locally.

Revised Horizontal and Vertical Control: We are merging the ULCN and CLCN, addressing, to a large extent, the horizontal accuracy problems of the CLCN [4,7,8], and establishing a global vertical network with the intent to create a new ULCN. Our new solution(s) include 3 changes in comparison to the existing ULCN and CLCN. 1) The camera angles are constrained to within 0.03° of their a priori (NAIF) values. 2) The coordinates of identifiable ULCN points are constrained to their estimated accuracy [1]. 3) Rather than assuming a spherical Moon, radii of all tie points are solved for. In our current preliminary ULCN 2005 solutions we constrain the radii to within 5 km of values interpolated from lidar and Clementine stereo. The constraint is large enough that in essence we are solving for the radii values. The mean absolute average change is ~200 m, thus showing radii are being recovered at that average accuracy or better. (See the Figure for our current radii model.) Since the end result is a combined horizontal and vertical network, this comprises the only lunar topographic model that is registered globally with horizontal control.

Future Work: In the near term we plan to finalize our ULCN 2005 solution. Future planned versions of this network may include the direct use of Mariner 10 and Galileo image measurements, the Lunar Orbiter control network currently being developed [9], and Clementine stereo [4]. We will also add ties to the current absolute lunar laser ranging retroreflector (LRRR) and Apollo lunar surface experiment package (ALSEP) coordinates [10].

Vertical Data Sources for the Moon.

Name	# points	Vert. Acc.	Comments
Clem. lidar	72,548	130 m	Sparse, between ±75°
Clem. polar stereo	319,8240	~1-2 km absolute	Polar only
Clem. stereo	?, not released	Few km absolute	Random coverage
Earth radar	~33.8×10^6	Few km absolute	Polar and Tycho only
Apollo lidar	5,629	Few km?	<20% coverage
Apollo stereo	Contour maps	As above	<20% coverage
ULCN	1,286	Few km?	Sparse, mostly nearside
ULCN 2005	273,090	< 1 km?	In preparation

References: [1] Davies, M. E. et al. (1994) *JGR*, 99, E11, 23,211-23,214. [2] Smith, D. E. et al. (1997) *JGR*, 102, E1, 1591–1611. [3] Rosiek, M. R. et al. (1998), *LPS XXX*, Abstract #1853. Rosiek, M. R., and Aeschliman, R. A. (2001) *LPS XXXII*, Abstract #1943. Rosiek, M. R. et al. (2001) Planetary Mapping 2001, ISPRS WG IV/9, http://astrogeology.usgs.gov/Projects/ISPRS/MEETINGS/. [4] Cook, A. C. et al. (2000), *JGR*, 105, E5, 12,023-12,033. [5] Margo, J-L. C. (1999) PhD Thesis, Cornell University. [6] Wu, S. S. C. and Doyle, F. J. (1990) in *Planetary Mapping*, R. Greeley and R.M. Batson, eds., CUP, 169–207. [7] Malin, M. and M. Ravine (1998) *Clementine High Resolution Camera Mosaicking Project*, TR, Malin Space Science Systems San Diego. [8] Cook, A. C. et al. (2002), *AGU Fall Meeting*, Abstract #P22D-09. [9] For details and numerous references, see http://astrogeology.usgs.gov/Projects/LunarOrbiterDigitization/. [10] Davies, M. E. and Colvin, T. R. (2000), *JGR*, 105, E8, 20,277-20,280.

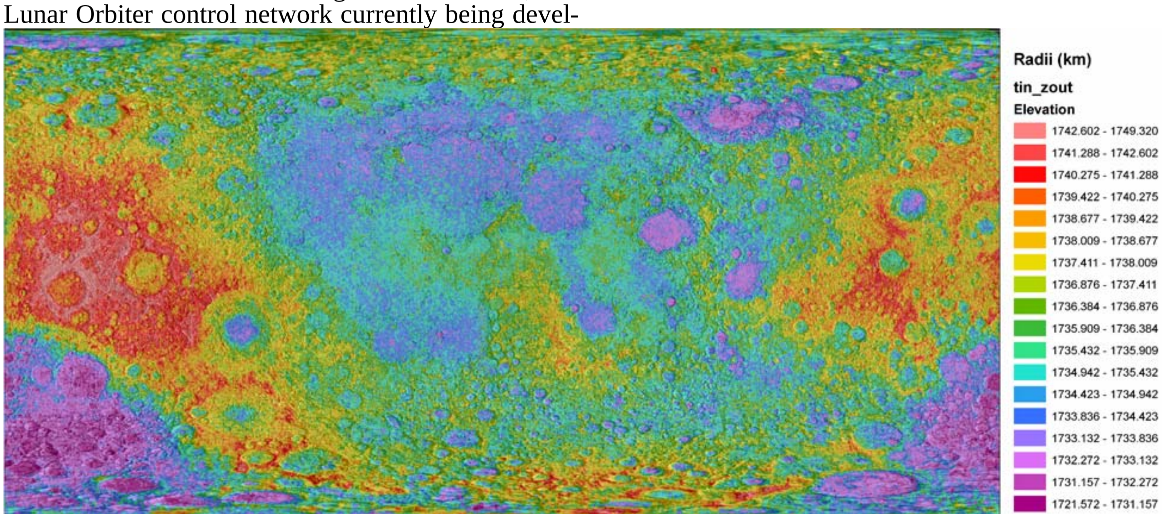

Figure: Tie point radii from preliminary ULCN 2005 solution. Shown as a global rectangular projection with north up and east to the right, and 0° longitude at center. This constitutes a preliminary improved lunar topographic model, with radii uncertainties of a few hundred m to 1 km.

Update on the Unified Lunar Control Network 2005. B. A. Archinal, M. R. Rosiek, R. L. Kirk, and B. L. Redding. U. S. Geological Survey (2255 N. Gemini Drive, Flagstaff, AZ 86001, USA, barchinal@usgs.gov).

Introduction: The Unified Lunar Control Network (ULCN) and the Clementine Lunar Control Network (CLCN) are generally accepted lunar control networks, both derived by M. Davies and T. Colvin at RAND. We address here our efforts to merge and improve these networks into a new network, ULCN 2005.

The ULCN was described in the last major publication about a lunar control network [1]. (See the table for statistics on this and the other networks discussed here.) Images for this network are from the Apollo, Mariner 10, and Galileo missions, and Earth-based photographs. The importance of this network is that its accuracy is relatively well quantified and published information on the network is available.

The CLCN includes measurements on 43,871 Clementine 750-nm images. The purpose of this network was to determine the geometry for the Clementine Basemap Mosiac (CBM) [2]. After the completion of the CBM, it was noticed that horizontal errors of 15 km or more were present in it and therefore in the CLCN [3-5]. These errors seem to have arisen for several reasons, including that only a few (22) near side points were fixed to ULCN positions, the camera angles were unconstrained, and the tie points were all constrained to lie on a mass-centered sphere with a radius of 1736.7 km.

ULCN 2005: We are merging the ULCN and CLCN and are addressing to a large extent the horizontal accuracy problems of the CLCN, with the intent to create a new ULCN. Our new solution(s) include 3 changes. 1) The camera angles are constrained to within 0.03° of their a priori (NAIF) values. 2) The coordinates of all identifiable ULCN points are constrained to their reported accuracy [1]. 3) Radii of all tie points are solved for. Our current results show horizontal position changes from the CLCN on average of ~7 km with some changes of dozens of km. See the Figure.

Future Work: In the near term we plan to finalize our ULCN 2005 solution. Future planned versions of this network may include the direct use of Mariner 10 and Galileo image measurements, the Lunar Orbiter control network currently being developed, and Clementine stereo [4]. We will also add ties to the current absolute lunar laser ranging retroreflector (LRRR) and Apollo lunar surface experiment package (ALSEP) coordinates [6].

Lunar Horizontal Control Net Comparison.

Name	# points	# images	Horz. Acc.	Vert. Acc.
ULCN	1,478	n/a	100 m to 3 km	Few km?
CLCN	271,634	43,871	Few km to some>15 km	Sphere
ULCN 2005	273,090	43,871	Few km	~ 1 km or less

References: [1] Davies, M. E. et al. (1994) *JGR*, 99, E11, 23,211-23,214. [2] USGS (1997) Clementine Basemap Mosaic, *USA_NASA_PDS_CL_30xx*, NASA PDS. [3] Malin, M. and M. Ravine (1998) *Clementine High Resolution Camera Mosaicking Project*, TR, Malin Space Science Systems San Diego. [4] Cook, A. C. et al. (2000), *JGR*, 105, E5, 12,023-12,033. [5] Cook, A. C. et al. (2002), *AGU Fall Meeting*, Abstract #P22D-09. [6] Davies, M. E. and Colvin, T. R. (2000), *JGR*, 105, E8, 20,277-20,280.

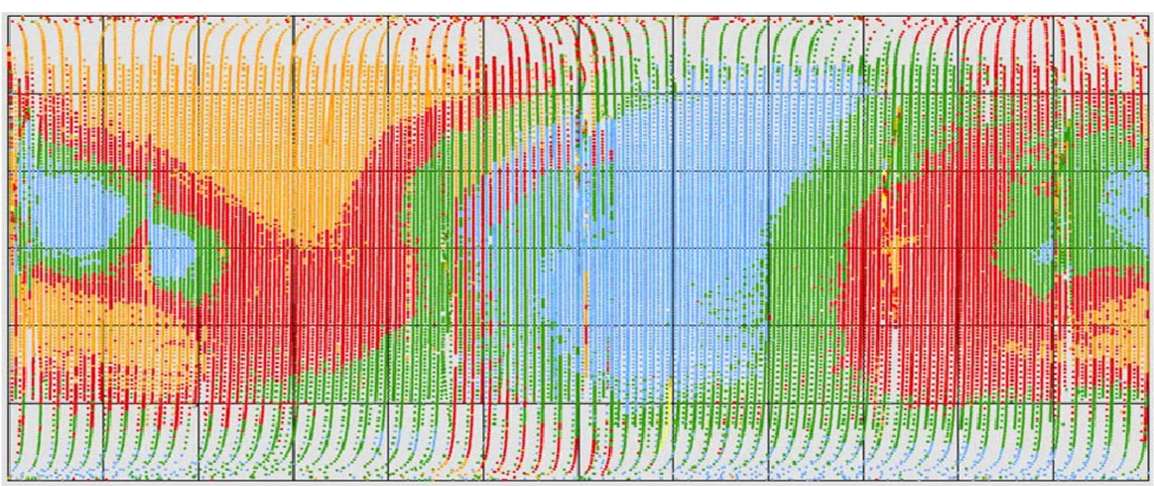

Figure: Change in image bore sight position of 43,857 images with camera angels constrained by 0.03° to a priori values, demonstrating the magnitude of the horizontal errors in CLCN. Shown as a global rectangular projection with north up and east to the right, and 0° longitude at center.

THE CRUX SEISMIC PROFILER FOR SHALLOW SOUNDING OF THE LUNAR REGOLITH. W. B. Banerdt[1], D. G. Albert[2], and W. T. Pike[3], [1]Jet Propulsion Laboratory, California Institute of Technology (M.S. 183-501, 4800 Oak Grove Drive, Pasadena, CA 91109; bruce.banerdt@jpl.nasa.gov), [2]U.S. Army Engineering Research and Development Center–Cold Regions Research and Engineering Laboratory (72 Lyme Road, Hanover, NH 03755; Donald.G.Albert@erdc.usace.army.mil); [3]Dept. of Electrical and Electronic Engineering, Imperial College London (Exhibition Road, London SW7 2BT, England w.t.pike@imperial.ac.uk).

Introduction: The recently undertaken Space Exploration Initiative has prompted a renewed interest in techniques for characterizing the surface and shallow subsurface (0-10s of meters depth) of the Moon. There are several reasons for this: First, there is an intrinsic scientific interest in the subsurface structure. For example the stratigraphy, depth to bedrock, density/porosity, and block size distribution all have implications for the formation of, and geological processes affecting the surface, such as sequential crater ejecta deposition, impact gardening, and seismic settling. In some permanently shadowed craters there may be ice deposits just below the surface. Second, the geotechnical properties of the lunar surface layers are of keen interest to future mission planners. Regolith thickness, strength, density, grain size and compaction will affect construction of exploration infrastructure in terms of foundation strength and stability, ease of excavation, radiation shielding effectiveness, as well as raw material handling and processing techniques for resource extraction. Note that relatively crude active seismic refraction methods were successfully employed to measured the first-order lunar regolith properties during the Apollo missions in the 1970's [1-5].

A modular integrated suite of instruments and software known as the Construction Resource Utilization eXplorer (CRUX) is being developed under a NASA ECP project to provide semiautonomous reconnaissance of the lunar and planetary surfaces. One component of CRUX is the SEIP instrument, a seismic profiler.

The seismic profiler will be used to complement the borehole and ground penetrating radar measurements which are also collected by CRUX. It can extend lunar regolith strength measurements tens to hundreds of meters away from a borehole, detect shallow ice inclusions or areas of ice-bonded soil, and determine the depth of the regolith. These goals will be accomplished by using an autonomous hardware and software system to measure the seismic compressional wave (P-wave) velocity in the shallow regolith. Because the seismic wave velocity is a direct measure of the elasticity and density of the material it passes through, it can be used to infer the strength as well as aspects of the composition [e.g., 6] and physical configuration (e.g., loose soil vs. soil with ice vs. rock) as a function of depth. The results of this system will be reported to CRUX for incorporation into areal analyses.

There are a number of methods available for data collection and interpretation. The primary method is the seismic refraction method. Here, an active vibrational source induces motion in the regolith that is recorded by the seismometers. The recordings are analyzed to determine horizontal travel time vs. distance, which is then converted to velocity vs. depth. This information can be then interpreted in terms of the shallow stratigraphy and mechanical properties. Other methods that will be investigated include surface wave analysis and microtremor analysis. These methods use more computationally intense analysis methods to determine the subsurface structure, and also provide additional information on the shear properties of the regolith. Data to implement any of these methods can be collected with the same hardware.

The seismic profiler hardware includes highly-sensitive seismometers to detect the wave arrivals, a source of the seismic waves (a solenoid-driven impactor or vibrator), communication (by cable or radio link), digitizers, and computational hardware. A low power source inducing a frequency sweep through a relatively long time series (seconds) will probably be used and the arrival times determined by correlation with the source function. A micro-machined silicon seismometer, utilizing electromagnetic feedback stabilization of DRIE-fabricated suspension is currently under development to achieve the demanding requirements on the receiver for sensitivity, frequency response, and linearity [7].

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INTERDISCIPLINARY RESEARCH ON SMALL LUNAR SEISMIC SIGNALS. W. Bruce Banerdt[1], Talso Chui[1], Nicholas Galitzki[1], Eugene T. Herrin[2], Ho Jung Paik[3], Konstantin Penanen[1], Doris Rosenbaum[4], Vigdor L. Teplitz[4,5], Joseph Young[1], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, e-mail: talso.c.chui@jpl.nasa.gov, [2]Department of Geology, Southern Methodist University, Dallas, TX 75275, [3]Department of Physics, University of Maryland, College Park, MD 20742, [4]Department of Physics, Southern Methodist University, Dallas, TX 75275, [5] NASA Goddard Space Flight Center, Greenbelt, MD 20771.

We discuss a proposal to perform sensitive seismic measurements on the Moon as part of NASA's lunar exploration program. The seismic signals will be used to determine the internal structure of the Moon, and to search for seismic evidence of strange quark matter, as postulated by particle physicists.

The absence of tectonic motion and atmospheric and ocean loading makes the lunar surface so quiet that the seismic background measured during the Apollo missions was dominated by instrument noise -- even though the seismometers were extremely sensitive even by today's standards. Since Apollo, important new science questions have arisen that can be answered by measurements of small seismic signals on the Moon below the noise level of the Apollo seismometers. In particle astrophysics, a dense form of matter known as Strange Quark Matter (SQM) was postulated by Witten [1]. SQM is made of up, down and strange quarks rather than neutrons and protons, which are made of up and down quarks. SQM is nearly charge neutral and has density of nuclear matter (10^{14} gm/cm^3). The theory also predicts that the interior of a neutron star is very likely made of SQM rather than neutrons; thus "neutron star" may be a misnomer. Small nuggets of SQM may have been formed as debris from the collisions of such compact stars. They may also have been formed during the Big Bang. With high mass and low abundance, the SQM nuggets would not interact appreciably with electromagnetic energy nor affect big bang nucleosynthesis. Hence, SQM is a suitable candidate for dark matter. As suggested by de Rujula and Glashow, a nugget of SQM may traverse a planet releasing detectable seismic energy along a straight line [2]. Such a phenomenon can be distinguished from a moonquake or a meteorite impact, which has a localized epicenter. The Moon would be a superlative detector of such events, if a few sensitive seismometers were deployed there, and if the structure of the Moon were known well enough for seismic modeling. However, the Moon's structure below ~700 km depth, including the size and state of its core, is almost completely unknown, as is the level of seismic activity on the far side. Therefore seismology, with sufficient sensitivity and coverage, can also benefit lunar science by providing a better understanding of the Moon's internal structure, formation and evolution.

We are pursuing the following activities to lay the groundwork for deploying a network of seismometers on the Moon. These activities are: 1) estimate the true seismic background of the Moon by extrapolating Apollo observations and modeling; 2) design and test a seismometer to learn how to reach the thermal noise limit and to understand the achievable limits of a lunar mission; and 3) analyze Apollo seismic data to identify constraints on SQM transit events and, with what we learn from 1), 2) and 3), model the discovery potential of plausible lunar seismometer deployment schemes. We will report the status of these activities, including the design and test of a low power seismometer read-out electronics using a tunnel-diode *LC*-oscillator, the design of a seismometer with an aim of reducing thermal noise, and a study to determine the available battery power for operation through the lunar night. Our earlier work on lunar search for SQM has been reported elsewhere [3, 4].

The proposed science is enabled by the access to the Moon to be provided by NASA's lunar exploration program, and will benefit the program by enriching its science contents. The result will lead to a deeper understanding of the structure and evolution of the Moon. Analysis of seismic activity will either identify SQM transit events, fundamentally changing our view of the Universe and its contents, or set valuable limits on the flux of SQM nuggets in a mass range not accessible to other efforts such as the NASA-DOE "AMS" spectrometer [5] or the NSF Antarctic "IceCube" neutrino detector [6].

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DEVELOPMENT OF RADIATORS FOR FUTURE MOON MISSIONS. M. Barmatz, T. Chui, and B. Zhang, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91109, Martin.B.Barmatz@jpl.nasa.gov.

Introduction: We are in the process of designing radiators that will capture the unique environment of the Moon to provide cryogenic capability for NASA to condense, purify, and store volatiles from the lunar regolith. From the Apollo missions, we learned that on average, 1 kg of Moon dust collected near the equator contained 0.56 ℓ of H_2, 0.17 ℓ of He, and 0.072 ℓ of N_2 at STP. The abundance of volatiles such as oxygen and nitrogen is likely to be highest inside permanently dark regions of polar craters, because the low temperature there favors binding of the gases to the lunar soil. Such abundant volatiles, and possibly water ice, can be used as life support resources and for processing into rocket fuel. Given the proper space environment, radiative cooling can be an effective and economical way to achieve cryogenic temperatures in space. We will present an analysis of radiator designs that take into consideration the specific lunar environment.

Approach: We will discuss a radiator design that is based on the fact that the direction of sunlight is never more than 1.55° away from the Moon's equatorial plane. Thus, if one is at the northern or southern hemisphere on the Moon, the sky is always dark. This observation should allow efficient radiative coolers to be deployed on the Moon. Such radiative coolers can also provide effective heat sinks to other electrical equipment and nuclear power sources. Furthermore, they can be used as heat sinks for cryocoolers to reach even lower temperatures or to increase cooling power. Once properly pointed at deployment, these radiators can provide reliable and uninterrupted cooling capability through the lunar day and night; the pointing direction will never need to be adjusted again. The geometry and the pointing of a radiator will depend on the lunar latitude where it will be deployed. We shall discuss two deployment locations - one at a lunar pole and one at the lunar equator to illustrate the simple design rules at these two limiting cases. The design for all other deployment locations will fall between these two cases. The most effective location for a radiator will be at a lunar pole. At polar locations, sunlight arrives from an almost horizontal direction and the radiator should point straight upward. Reflected sunlight from the Earth also arrives from an almost horizontal direction. A conical radiator design is advantageous because any sunlight that enters the conical sunshield will be reflected into space. We will discuss a radiator design containing a number of concentric conical radiation shields with narrower cone angles for the inner shields. This arrangement allows radiation to be reflected between an outer shield and an inner shield. Each successive reflection directs the radiation outward toward deep space. For deployment at the equator, the design of the radiator will be difficult; and radiators there will not be as effective as at the poles. We are also currently developing a finite element model to better understand radiator-cooling power versus temperature to optimize the design.

Application. A simple radiative cooler is the obvious choice for the storage of cryogens like oxygen and nitrogen where large cooling power is not required. On average, a human being converts ~ 0.85 kg of oxygen into carbon dioxide in a day. We will present calculations showing that only 0.8 W is required to continuously purify oxygen for one astronaut. A 1 m^2 surface-area radiator can provide ~ 3.2 W of usable cooling power. Thus, to first order a 1 m^2 radiator surface is sufficient to purify enough oxygen to support ~ 4 astronauts continuously. Alternatively, one can support fewer astronauts and store the excess liquid oxygen produced. These conclusions for this design will be compared with the performance of a Stirling cycle cryocooler [1].

Moon dust. Micron-sized charged dust particles are pervasive on the Moon's surface and will cover objects such as solar panels, astronaut's suits, and radiators [2]. These particles can become charged in the presence of UV radiation coming from the sun. Electromagnetic forces are known to shape the spatial and size distribution of these particles leading to levitation and rapid transport [3]. The degradation in the efficiency of a lunar radiator due to Moon dust must be determined before final designs are completed. If this degradation is sufficiently large, the development of methods to remove the dust from surfaces may be necessary. We are in the process of establishing collaborations with research groups at other NASA centers that can provide a simulated Moon dust environment where we can test a prototype radiator to evaluate the level of the expected degradation.

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LUNAR ORBITER DIGITAL MOSAICS: A FOUNDATION FOR LUNAR RECONNAISSANCE MAPPING. T. Becker, L. Weller, L. Gaddis, D. Soltesz, D. Cook, A. Bennett, T. McDaniel, B. Redding, J. Richie, Astrogeology Team, U.S. Geological Survey, 2255 N. Gemini Drive, Flagstaff, AZ (tbecker@usgs.gov).

Introduction: We have digitized a subset of the Lunar Orbiter photographs [1, 2] and used these data to create a global, cartographically accurate mosaic of the Moon (**Figure 1**). Coverage is provided by combining LO III, IV and V medium- (MR) and high-resolution (HR) frames. Geodetic control for these data is provided by the new, improved Unified Lunar Control Network 2005 [3, 4]. These LO data and mosaics are being made available on the LO Web site (http://astrogeology.usgs.gov/Projects/LunarOrbiterDigitization/) [5-9]. Both full and reduced resolution data will be released, and explanations and examples of frame processing steps and methods are provided. In the next year, we plan to release these digital data as PDS-compatible products and on the Map-a-Planet Web site (http://pdsmaps.wr.usgs.gov/maps.html).

Summary: This project to digitize and cartographically process the LO film represents the revival of the historic LO photographic collection. This invaluable, high-quality dataset has previously been available as raw film strips, constructed frames on negatives, hardcopy prints, and as low-resolution reproductions in books and online. This cartographic task (funded by the NASA Planetary Geology and Geophysics Program) will produce a widely available digital archive that will serve as an invaluable foundation for future lunar reconnaissance mapping and data analysis.

References: [1] Hansen (1970), NASA SP-242. [2] Bowker and Hughes, (1971), NASA SP-206. [3] Archinal et al. (2005), LPS XXXVI, #2106. [4] Archinal et al. this volume. [5] Gaddis et al. (2001), *LPS XXXII*, #1892. Lunar Orbiter Pilot Project: http://astrogeology.usgs.gov/Projects/LunarOrbiterDigitization/. [6] Gaddis et al. (2003), *LPS XXXIV*, #1459. [7] Becker et al. (2004), *LPS XXXV*, #1791. [8] Becker et al. (2005), *LPS XXXVI*, #1836. [9] L. Weller et al., this volume.

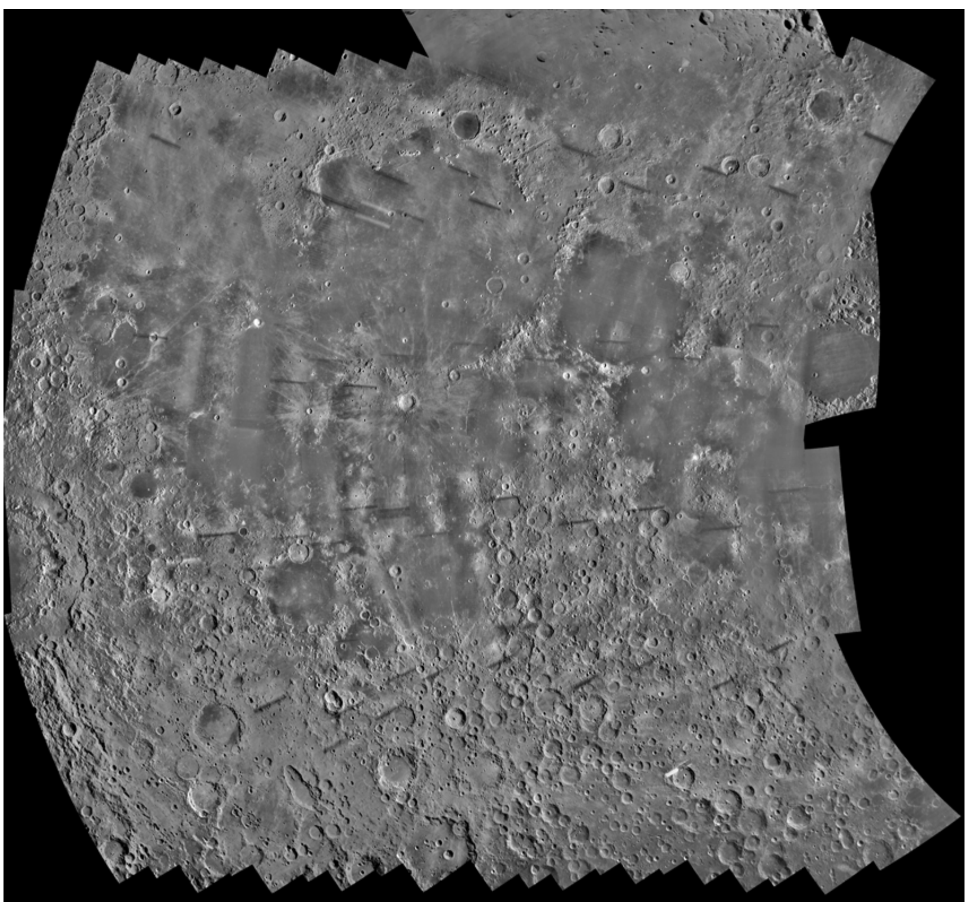

Figure 1. LO mosaic of the lunar near side, with Copernicus crater and Sinus Aestuum at the center. Simple Cylindrical projection, high-pass filtered view of 91 LO IV high-resolution frames.

PERFORMANCE-BASED ENGINEERING FOR LUNAR SETTLEMENTS. Haym Benaroya benaroya@rci.rutgers.edu, Department of Mechanical & Aerospace Engineering, Center for Structures in Extreme Environments, RUTGERS University, 98 Brett Road, Piscataway, NJ 08854

Introduction: Concepts for lunar base structures have been proposed since long before the dawn of the space age. The emphasis below is on structures for human habitation, a technically challenging fraction of the total number of structures likely to comprise the lunar facility. The test for any proposed lunar base structure is how it meets certain basic as well as special requirements. On the lunar surface, numerous constraints must be satisfied by all designs. These are different from those for terrestrial or orbital structures, as will be discussed later. A number of structural types have been proposed for lunar base structures. These include concrete, metal frame, pneumatic, and hybrid structures. In addition, options exist for subsurface architectures and the use of natural features such as lava tubes. Each of these approaches can in principle satisfy the various and numerous constraints, but differently.

Reliability: This paper examines risk and reliability issues surrounding the establishment of structures for human habitation on the Moon. Human safety and the minimization of risk to "acceptable" levels is always a top consideration for any engineering project. The Moon offers new challenges to the engineering designer. Minimization of risk implies in particular structural redundancy, and when all else fails, easy escape to safety for the inhabitants. The key word is "acceptable." It is a subjective deliberation, deeply rooted in economic considerations.

What is an acceptable level of safety and reliability for a lunar site, one that must be considered highly hazardous?

Such questions go beyond engineering considerations and must include policy considerations: Can we afford to fail?

Reliability is a specialized term for the analysis and design of systems where certain aspects of the environment and system have associated uncertainties. Thus, design requires explicit accounting of evolutionary processes that are inherently nondeterministic. This fact makes estimation of risk and reliability design complex activities.

The problem of designing a structure for construction on the lunar surface is a difficult one, discussed here only in relation to risk and reliability. Some important considerations necessary in a detailed reliability study include:

- the relationships between severe lunar temperature cycles and structural and material fatigue, a problem for exposed structures,
- structural sensitivity to temperature differentials between different sections of the same component,
- very low-temperature effects and the possibility of brittle fractures,
- outgassing for exposed steels and other effects of high vacuum on steel, alloys, and advanced materials,
- factors of safety, originally developed to account for uncertainties in the Earth design and construction process, undoubtedly need adjustment for the lunar environment, either up or down depending on one's perspective and tolerance for risk.

Many of these considerations are well understood in a basic sense, and need to be expanded upon for the lunar site. Some of these discussions have started, in particular regarding the design process for an extraterrestrial structure. Specifically:

- What failure rate is acceptable?
- What factors of safety, and levels of redundancy, are necessary to assure this failure rate?
- What failure rate is acceptable?

Next, man-made risks are to be assessed. What factors of safety, and levels of redundancy, are necessary to assure this failure rate?

Redundancy is a separate question. Once a basis has been set for acceptable risk and safety factors, the designer must be ingenuous in the conceptual design, optimizing the design so that overall risk is as close as possible to the acceptable level. In addition, risk should be distributed throughout the site in accordance with the criticality of the various parts to the overall mission. This is a difficult problem, requiring the study of competing structural concepts.

Other related studies must be made of: logistics, inventories, payload delivery options, redundancy of design, ease of repair and reconditioning, smart and self-repairing systems. A detailed introduction and discussion is provided in [1].

References: [1] Benaroya, H. (1994) *Structural Safety* 15, 67-84.

USE OF LUNAR SOIL AND LUNAR SURFACE ROCKY MATERIALS IN INSULATION OF BUILDINGS ON THE MOON.
Sz. Bérczi[1], B. Boldoghy[2], J. Kummert[2], T. Varga[3], I. Szilágyi[3], [1]Eötvös University, H-1117 Budapest, Pázmány P. s. 1/a., Hungary (bercziszani@ludens.elte.hu), [1] Ferroelektric Engineering Pan Konceptum Ltd., H-1116 Budapest, Vasvirág sor 72., Hungary, (konceptum@vipmail.hu) [3]VTPatent Agency, H-1111 Budapest, Bertalan L. u. 20., Hungary (info@vtpatent.hu),

Summary: The fine particle sized dust available on the surface of the Moon can be used for the thermal insulation of the lunar buildings. As location of the buildings we suggest the ditches or grooves, where lunar buildings can be buried directly into the subsurface, in the regolith for insulation.

Introduction*:* Surveyor, Luna and Apollo Missions measured the main characteristics of the lunar soil, [1], of heat flow [2], mechanics [3]. According to these data analog material consisting of glass-rich basaltic ash sample, was developed [4]. Even electrostatic characteristics and charging properties of the lunar soil were measured [5]. We used these data for the planning engineering of a permanent lunar base construction. For human beings it is necessary to create internal spaces in buildings with conditions similar to those of the Earth. Insulation plays a central role because the heat loss between the inner temperated and the outer space is determined mainly by the thermal insulation system of the building. As the lunar dust consists of fine particles, it has excellent thermal insulation characteristics. This dust has unlimited availability on most part of the lunar surface. For steady temperature of the lunar architecture this property of the lunar regolith is very useful.

The principles of the use for thermal insulation:

Lunar dust consists of fine particles. The particles are products of mainly mechanical fragmentation therefore they have large surface with less surface contacts as compared to terrestrial rounded grains. This few contact between the particles results in a loose structure. In such a grain system conduction transport of the heat is very little, heat is forwarded to the neighboring particles mainly by radiation (this form of thermal energy transport is less effective, than conduction).

Compared to the conditions on the Earth the significant difference lies there, that on the Moon the thermal conductivity of the dust is considerably lower than on the Earth due to the absence of atmosphere and liquid materials, therefore we assume, that the lunar soil can be used as thermal insulator in its original texture. Because of the small grains size, if used as building material this soil behaves as fluid, similar to riverbed sand available in some parts of the Earth.

Utilizing the lunar regolith in architectural constructions: On the Moon a lot of conditions are missing that are present on Earth and restrict or prevent the use of the fine grained dust. Due to the lack of atmosphere there is no wind, no draught and no dust blast is possible.

According to our proposal [6] the possible methods of using lunar dust as thermal insulator in constructing lunar architectures are as follows: 1) In its genuine dust form, a) by loading (with preliminary collection) as thermal insulating cover, b) its partial advantage is, that in case of a possible impact it acts as moderator as a material behaving like a liquid material, c) it gives protection against radiation.

It is suitable for surrounding the building from every direction. In block form: 1) using light binding material creating a crust on its outer surface a) as solid building material, with binding material to be produced on the spot (e.g. salt, which can be NaCl) and b) as dust, as thermal insulating filling material - to fill up hollows and certain parts of existing structural elements. For example the pre-fabricated frame structure is assembled on the Moon – creating the frame and the crust and filling up the space around the building (below, above, on the sides around) with moon dust or with thermal insulating material made of the dust. Thermal insulation is made on the spot, e.g. with building, thermal insulating materials made on moon dust. Another solution for its use is putting lunar soil or regolith gravels into bags (though it is not so useful as thermal insulator, but can be used as industrial building element. It can be used as uniform building material).

The steps of the building technology: 1) A horizontal surface is prepared of coarse particles, (it is compacted) in a ditch or in the bottom of a valley, 2) The pre-assembled building is located on the prepared surface, 3) The frame structure is fixed, 4) The pan will be filled with thermal insulating dust, which will give protection against radiation, heat and mechanical damages, 5) An appropriate thickness of dust layer will be formed from below, from the sides as well as from above. (In this technological step the behavior of the lunar dust as liquid, is used, so it envelops the whole object.) Finally the dust can entirely surround the whole thing. Thermal insulation is necessary downwards as well [7].

Further steps: transfer, exchange, extension: The building to be located is vibrated into the dust. A hollow can be created by vibration and material transport where the building can be placed. Size: the size of the valley is approximately 50-100 m, depth 20-40 m. The thickness of the dust surrounding the building – 20-30 m. (It would be preferable first to build a preassembled object, e.g. like the space station unit, and surround it with lunar dust envelope. This way the production and operational costs could be significantly lower).

The advantage of our approach*:* It requires the necessity of delivery of only very few devices while using local materials available on the Moon to a maximum extent. Human resources: min. 2, preferably 4 people. It is worth developing a 1) mobile ensuring arrangement and manipulation of both solid and dust-like materials, 2) operation of mechanical devices is possible by partial robot or remote control mode.

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CARBON MONOXIDE SILICATE REDUCTION SYSTEM. Mark Berggren, Robert Zubrin, Stacy Carrera, Heather Rose, and Scott Muscatello, Pioneer Astronautics, 11111 W. 8th Ave., Unit A, Lakewood, CO 80215, mberggren@pioneerastro.com

Introduction: The Carbon Monoxide Silicate Reduction System (COSRS) is a novel technology for recovering large amounts of oxygen from lunar soils. Soils are sequentially subjected to iron oxide reduction by carbon monoxide, in-situ deposition of carbon throughout the soil by carbon monoxide disproportionation catalyzed by metallic iron, and finally high-temperature reduction of silicates by the deposited carbon. Figure 1 shows the process schematic.

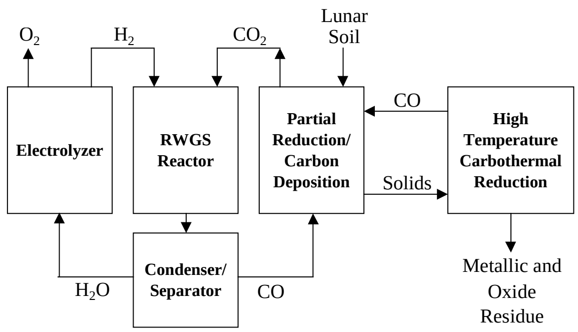

Figure 1: COSRS process schematic.

Approximately 2 kilograms of oxygen per 100 kilograms of soil are recovered by the initial iron oxide reduction step. Up to an additional 28 kilograms of oxygen per 100 kilograms of feed soil are recovered during the carbothermal reduction step. Process gases are fed to a Reverse Water Gas Shift (RWGS) unit for regeneration of carbon monoxide and recovery of oxygen by electrolysis from the resulting water. The COSRS-RWGS-electrolysis is a closed system with only small losses of carbon to the spent soil. The metallic and oxide slag residues have value for in-situ resource utilization.

A six-month, NASA SBIR Phase I COSRS program was conducted in 2005. Each unit operation was separately demonstrated in the laboratory using both JSC-1 lunar and JSC Mars-1 soil simulants. A final integrated, closed-loop, COSRS-RWGS-electrolysis experiment produced oxygen from JSC-1 lunar soil simulant.

Program Accomplishments: Thermodynamic evaluations led to selection of a substoichiometric carbon:silicon dioxide ratio to minimize carbon losses to the carbothermal reduction residue. Under conditions selected for Phase I demonstration, about 15 kilograms of oxygen per 100 kilograms of soil were recovered from both lunar and Mars soil simulants using the COSRS process at temperatures up to 1,600^{o}C. Process leverage (mass of oxygen recovered divided by mass of carbon lost to the residue) on the order of 25 was achieved in each case. COSRS was successfully integrated with an RWGS-electrolysis system during iron oxide reduction of lunar soil simulant. The integrated system produced the desired solids product and demonstrated that minor gas constituents stabilize at very low concentrations after extended periods in the closed RWGS loop.

Carbothermal reduction residues contained spheres of iron and silicon metal above a glassy oxide matrix. Figure 2 shows the metallic and oxide phases in JSC-1 carbothermal reduction residue. Electron microprobe analysis of the residue confirmed distinct separation of the metal and oxide phases, opening the possibility of byproduct separation and recovery.

Figure 2: JSC-1 carbothermal reduction residue.

The Phase I results demonstrated oxygen recoveries of five times that possible using hydrogen as a reductant. Up to ten times more oxygen than could be recovered by hydrogen reduction is possible by increasing the mass of carbon deposited before carbothermal reduction. Further trade studies are needed to optimize the carbon:silicate ratio with respect to oxygen recovery and leverage.

Acknowledgement: This work was conducted under NASA Small Business Innovation Research (SBIR) funding. Kris Lee was the NASA JSC Contracting Officer's Technical Representative (COTR).

MARS AQUEOUS PROCESSING SYSTEM. Mark Berggren, Robert Zubrin, Heather Rose, Melanie West, Dan Harber, James Kilgore, Anthony Muscatello, and Molly McNulty, Pioneer Astronautics, 11111 W. 8th Ave., Unit A, Lakewood, CO 80215, mberggren@pioneerastro.com

Introduction: The Mars Aqueous Processing System (MAPS) is a novel technology for recovering oxygen, iron, and other constituents from lunar and Mars soils. The closed-loop process selectively extracts and then recovers constituents from soils using sulfuric acid and bases. The emphasis on Mars is production of useful materials such as iron, silica, alumina, magnesia, and concrete with recovery of oxygen as a byproduct. On the Moon, similar chemistry is applied with emphasis on oxygen production from iron oxide concentrate.

MAPS is significant because it can be co-developed for Mars and Moon applications, thereby reducing risks and costs. The process would be commissioned first for oxygen production on the Moon using reagents brought from Earth and recycled for reuse. Modular enhancements for manufacture of additional products would then be implemented on the Moon. On Mars, reagents would be derived from in-situ resources including magnesium sulfate and water, allowing a wide range of materials to be produced from indigenous resources.

A six-month, NASA SBIR Phase I MAPS program was completed in 2004. Work is continuing under a two-year Phase II program to establish a design basis for lunar oxygen production, lunar materials production, and Mars materials production.

Phase I Accomplishments: Pioneer Astronautics achieved the Phase I objectives by demonstrating the major MAPS unit operations in the laboratory. Magnesium sulfate was extracted from a Mars duricrust simulant and then recovered by crystallization from solution. Magnesium sulfate was decomposed to sulfur dioxide and oxygen gas while generating magnesium oxide. Sulfur dioxide and oxygen were converted to sulfuric acid following sorption in water using a low-temperature, liquid-phase catalytic process. Acid produced by this method was used to selectively extract iron and other constituents from JSC Mars-1 soil simulant. Iron was recovered from solution as a high-grade oxide concentrate. The iron oxide was reduced to iron at temperatures less than 750^{o}C. Other byproducts, such as alumina and silica, were also recovered from solution by controlling time, temperature, and acidity. One sample of structural material formed from spent simulant and extracted magnesium compounds exhibited compressive strength of over 800 psi.

Figure 1 illustrates the MAPS processing capabilities for Mars soils.

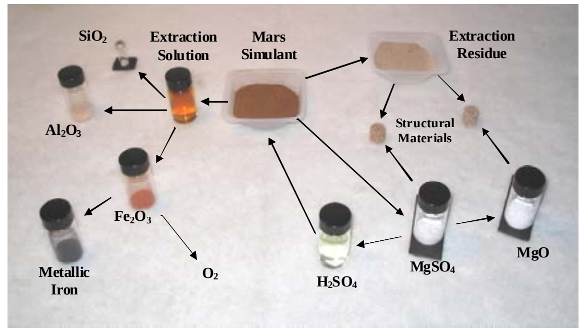

Figure 1: MAPS processing capabilities.

A subset of MAPS was demonstrated to be equally useful for lunar applications. Iron oxide was extracted from JSC-1 lunar soil simulant in the laboratory. High-grade iron oxide concentrate (>80% as Fe_2O_3) recovered from lunar soil using MAPS technology would reduce thermal power requirements for lunar oxygen production by an order of magnitude due to the reduced mass of bulk material to be heated. In addition, the reduced iron would then be available in a useful form for manufacturing structural materials.

Phase II Status: Work is in progress to develop MAPS design data for the Moon and Mars. Efforts center on conducting laboratory experiments in parallel with thermodynamic modeling to optimize process parameters and to establish material and energy balances.

An improved metals recovery system using crystallization of sulfate salts via temperature adjustment of the metal-laden extraction solution is being investigated. This alternative recovery method greatly reduces the acid regeneration requirements resulting from earlier base precipitation methods used for metals recovery.

Preliminary research to extract silica from lunar soil has shown promise. Relatively weak acid solution is used to extract silica from spent residue following metals extraction. Temperature and incubation time are used to control the silica dissolution and polymerization steps leading to precipitation prior to recovery by solid-liquid separation.

Acknowledgement: This work is being conducted under NASA Small Business Innovation Research (SBIR) funding. Kris Romig is the NASA JSC Contracting Officer's Technical Representative (COTR).

The Enabling Role of ISRU for Space Commercialization. B. R. Blair[1], G. B. Sanders[2], M. E. Nall, K. P. Heiss, S. H. Anderson, P. A. Curreri, K. R. Sacksteder, E. E. Rice, E. D. McCullough, M. B. Duke, T.C. Maglessen, [1]CCACS, Colorado Schol of Mines, 1310 Maple St., Golden, Colorado, 80401, bblair@mines.edu, [2]Propulsion & Fluid Systems Branch, NASA/JSC, MC-EP4, Houston, TX, 77058, gerald.b.sanders@nasa.gov.

Introduction: A series of NASA-sponsored meetings were held in the spring of 2005 to define a capability roadmap for in-situ resource utilization (ISRU). One of the subcommittees that formed during this activity examined the theme of space resource commercialization. The rationale behind integrating the topic of commercial activity into a capability roadmap stems from the strong interdependence between ISRU and commercialization. This rational is further elaborated below.

ISRU enables commercialization: The technologies needed to extract propellant and materials for NASA missions will lead to a wide range of potential products and services that will become the economic foundation of a sustainable and growing space economy. Products include propellant, life support consumables, building/construction hardware and materials, and raw materials. Services include power, construction, maintenance, and communications. From a practical perspective, government investment in ISRU technology will reduce the technical risk associated with entrepreneurial space ventures and also help create the industrial complex for commercial enterprise. Analogies include the early US aviation industry, the railroads, and the national highway system.

Commercialization enables ISRU: Industrial expertise in mining, material extraction, process control, and other areas will become the foundation of ISRU technology. A vast reservoir of technical and business experience resides within US industry, and will serve as the basis for building the tools and capabilities needed for sustainable planetary surface activities. In addition, the new technologies required for planetary exploration and resource development could be utilized to improve existing industrial products and services, creating a feedback loop that empowers industrial partnerships by offering near-term benefits. By activating early commercial partnerships, a win-win situation will be created that rewards the participation of non-aerospace industries in the Vision for Space Exploration.

Transcending budget restrictions: Commercialization can provide added capital as well as capability to NASA. By facilitating and nurturing commercial ISRU ventures, NASA can leverage its budget by creating a channel to access private capital. The potential for off-budget augmentation of human exploration capabilities and infrastructure exists in many areas of ISRU with commercial potential. In addition, while the NASA budget is fixed, private capital is flexible in its ability to respond to opportunities. Collaboration between NASA and commercial enterprise will generate substantial return-on-investment in product, infrastructure, and the future opportunities that will inevitably follow.

NASA Strategic Goals: The commercial development of the Moon meets and enables strategic goals of the Vision for Space Exploration Vision. ISRU technology development can increase near-term, non-traditional, commercial participation in human space exploration, furthering US economic interests in both a short and long-term perspective. Commercial activities could provide both products and services that could support reusable space transportation and NASA exploration missions. Commercially supported ISRU offers a clear path to reusable, evolvable, extensible and sustainable space systems and capabilities.

Policy and Law: NASA could serve as an enabling voice in promoting policies for sustainable space resource development. Proactive opportunity management could activate a rich set of early commercial ISRU capabilities that could benefit human space exploration and enhance U.S. economic interests. By playing an integral role in facilitating ISRU for government and commercial space systems development, NASA will expand precedential space resource policy. In order to remain sustainable, commercial ISRU enterprise must embrace long-term markets that extend well beyond government-funded human space exploration.

References:

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Bombardment History of the Moon: What we think we know, what we don't know, and how we might learn more. **Donald Bogard**, ARES-KR, NASA-JSC, Houston, TX 77058

The heavily cratered surface of the moon is a testimony to the importance of impact events in the evolution of terrestrial planets and satellites. Lunar impacts range in scale from an early intense flux that defined the surface geology of the moon, down to recent, smaller impacts that continually generate and rework the lunar regolith. Densities of larger craters on lunar surfaces of dated age define an impact flux over time that serves as the basis for estimating surface ages on other solid bodies, particularly Mars. The lunar cratering history may address aspects of Earth's evolution, such as the possible role of early intense impacts on the atmosphere and early life and possible periodicity in large impact events in the more recent past. But, much about the lunar impact history remains unknown..

Densities of craters on some lunar mare surfaces and crater ejecta deposits, for which we have estimated formation ages, suggest an approximately constant lunar impact rate for larger projectiles over the past ~3.5 Gyr. It is unknown if the impactor flux during this time experienced significant shorter term variations, but this has been suggested. This question can be addressed by determining formation times of many (e.g., ~100) craters of small to intermediate size with ages ≤1 Gyr. Such age determinations can be made by radiometric dating of strongly heated or melted ejecta or by determination of near-surface exposure times to cosmic rays, and both methods may require sample return to Earth. Both methods also require that we definitely associate rocks with a specific crater, which will require that each crater be examined in some detail, either robotically or by humans. Another approach already applied has been to measure K-Ar and exposure ages in many small samples of impact melts separated from an Apollo-returned sample of regolith, and to examine these statistically. Conclusions that can be derived from this approach are not completely clear.

A few dated surfaces older than 3.5 Gyr imply a much higher impactor flux in the earliest lunar history, although we have no direct data prior to ~4 Gyr ago. Dating of returned lunar rocks have yielded approximate formation ages of a few major lunar basins, e.g., Imbrium at ~3.85 Gyr and Serenitatis at ~3.87 Gyr. These ages and three additional observations support the idea of a period ~3.8-4.0 Gyr ago when the impact flux was much higher than either before or after this time. These are: 1) the observation that radiometric ages of most lunar highland rocks were reset in the time period of ~3.8-4.1 Gyr ago; 2) the argument that the mass accreted to the moon by basin-forming projectiles ~3.8-4.0 Gyr ago was too large to extrapolate back into earlier lunar history; and 3) the observation that eucrite meteorites, thought to derive from the ~550 km diameter asteroid, Vesta, show a distribution of K-Ar ages that resembles the distribution of ages of lunar highland rocks. This proposed period of enhanced flux has been called the impact cataclysm or sometimes the heavy late bombardment. On the other hand, some workers have argued that this period of a higher impact rate was the tail end of a much higher flux remaining from lunar formation.

The source of the early impactors and their compositions remains largely unknown. This ignorance extrapolates to early Mars and the Earth, not only for the effects of impactors on crustal characteristics, but also in atmospheric evolution and possibly early life. Were these objects residues from feeding zones during planet formation, possibly implying significant variations? Are they scattered objects from the asteroid belt, implying affinities with meteorites? Are they Kuiper belt objects, scattered as the orbits of the outer planets migrated, suggesting that they may have been volatile rich?

Improving our knowledge of the early lunar bombardment may be difficult, because surface crater densities are often saturated and ejecta from such impacts has been heavily reworked, disturbing the chronology. Important new information could be gained by dating specific large basins such as South Pole-Aitken, the largest and oldest on the moon, and large craters from the far-side northern highlands, which represents the oldest crust least affected by large near-side basins. Correlating rock ages with chemical type may also be informative. Again, acquiring the optimum samples for dating is key.

Lunar Directed Science and Suggested Mission Architecture and Mobility: An Overview

Donald D. Bogard, ARES-KR, NASA, Johnson Space Center, Houston, TX 77058

The Moon is a cornerstone for understanding some major early planetary processes. Justification of this statement comes from the following considerations about the moon: It preserves the remnants of the magma ocean style of planetary differentiation. It illustrates a style of early planetary asymmetry that is related to early differentiation processes. It illustrates a pathway of planetary evolution that is related to a style of planetary accretion and differentiation. It illustrates the full crustal formational and magmatic history of a cooling planetary body. It recorded and preserved the early impact environment of the inner solar system. Interactions between a planetary surface and space are preserved in the lunar regolith. It represents the volatile-poor end member for planetary volatile abundance.

From this perspective, a working group of lunar scientists was formed in 2004 as the Moon-Mars Science Linkage Science Steering Group (MMSLSSG) and given the following charter (in part): To develop an analysis of the potential ways in which the scientific objectives for the exploration of Mars can be advanced through scientific investigations of the moon (1). In conducting this analysis, the MMSLSSG considered broad aspects of lunar geology, geochemistry, and geophysics that warrant additional scientific investigations. In constructing their report, the MMSLSSG divided lunar-directed science into several topical areas, summarized the type of new science needed for each science topic, and listed for each topic several kinds of measurement sets that could address this science.

I have taken this report and reformatted it with minor changes. I then assigned the types of mission architecture and/or mobility that may best be used to obtain the desired science data sets. Among the mission types assigned are: lunar orbiter; multiple robotic landers in diverse lunar sites; multiple human landers in diverse sites; multiple site landers with sample return to Earth; robotic rovers from a lunar base; human tended rovers from a human base; human near-base activity. This effort is intended to indicate what types of scientific investigations may best be performed with certain types of lunar mission architecture and/or mobility. This effort is strictly my own and is intended to stimulate discussion between acquisition of specific scientific data sets and development of the NASA lunar exploration program. Not surprisingly, certain types of scientific data are probably best attained from orbit; some types are best obtained by access to multiple sites widely dispersed across the lunar surface; some types are best acquired near a human base, and other types probably require a sample return to Earth.

A poster will present this information.

(1) Members of the MMSLSSG were: Shearer, C., Beaty, D.W., Anbar, A., Bogard, D., Campbell, B.A., Duke, M., Gaddis, L., Jolliff, B., Lentz, R.C.F., McKay, D., Neumann, G., Papanastassiou, D., Phillips, R., Plescia, J., and Wadhwa, M. (2004). Findings of the Moon-Mars Science Linkage Science Steering Group (MMSSG). Unpublished white paper, 29 p, posted October, 2004 by the Mars Exploration Program Analysis Group (MEPAG) at **http://mepag.jpl.nasa.gov/reports/**

FUNCTIONAL PROGRAM OF BUILDINGS FOR CONDITIONS ON THE MOON. B. Boldoghy[1], J. Kummert[1], Sz. Bérczi[2], I. Szilágyi[3], T. Varga[3], [1] Ferroelektric Engineering Pan Konceptum Ltd., H-1116 Budapest, Vasvirág sor 72., Hungary, (konceptum@vipmail.hu), [2]Eötvös University, H-1117 Budapest, Pázmány P. s. 1/a., Hungary (bercziszani@ludens.elte.hu), [3]VTPatent Agency, H-1111 Budapest, Bertalan L. u. 20., Hungary (info@vtpatent.hu),

Summary: Our functional environment planning of the lunar base determines the primary and secondary functions of the buildings, and elaborates their optimal connections.

Introduction: The aim of our proposal is to specify the system of functions of buildings required in lunar conditions and to find the most appropriate connections between them.

Discussion: In the function of the building the requirements of the planned activities are expressed. They contain primary and secondary functions and attached secondary functions (i.e. primary: accommodation, secondary: toilet, bathroom, kitchen). The levels of design of the building's functional program: 1) General 2) Concrete.

The primary functions of a Lunar Base are: 1) temporary human stay 2) permanent human stay with services, 3) any task specified: research, scientific activity, 4) industrial activity: storing, production. These functions imply requirements: 1) temperated – or not, different temperature zones, 2) with atmosphere or without, 3) external functional links with air-locks, etc. Connecting nodes link spaces of various conditions, e.g. with or without air, filled with gas, temperated or not, etc. also by air-locks.

Transportation: The transportation is of high priority: 1) personal, 2) goods, equipment, preferably in standard containers. Forwarding goods require additional tasks compared to Earth conditions: 1) finding solutions for air-locks, 2) maintaining certain temperature levels on given special places, 3) different levels of lighting, 4) finding solution for continuous electronic monitoring.

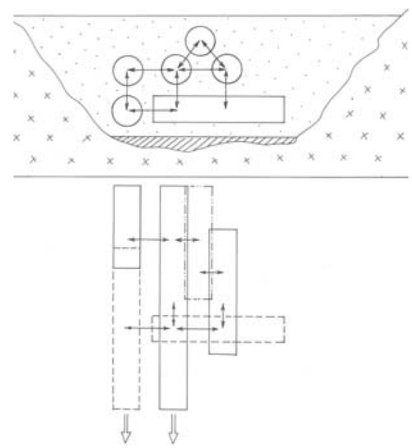
Additional functional issues*:* 1) Gas-proof joining of conduits of node and pipe systems, fire safety, 2) Fire-protections systems to different levels, 3) Special function for human environment 4) Fitness, wellness functions – for human stay, 5) Entertainment, intellectual, cultural functions.

Operating functions: 1) exchange of gas, oxygen supply, extraction of CO_2 – relative methods – vegetation, bacteria culture, 2) vapor technology, air cleaning – relative engineering background, 3) disposal of biological waste, 4) water recirculation – relative premises, engineering.

Essential elements of our proposal: 1) assessment of functions depending on the function of the building, 2) determining primary and secondary functions, 3) determining functions that can be unified, 4) working out relative optimal structural and technical resolutions, 5) establishing harmony between function and structure of buildings.

Highlights of the functional program according to our proposal*:* 1) minimizing length of transport and delivery routes, 2) optimizing movements on and between levels, 3) location of module units in space. (Movements of devices, equipment of large bulk and volume – on level and linear – are also involved in our organization program of functional units, in order to minimize heat-loss). Minimizing of necessary air-locks is an economic aspect as well as a security issue, as every air-lock is a source of failures, source of accident, loss of pressure and gas, which can considerably increase costs.

Possibility of extension: All the functions should be created so, that they could be continuously extended on module bases and extension should involve the possibility of the extension of the functional tasks. These functions are those that serve as the base of building structures, resulting from it, the base of the structure of the settlement should be established keeping in mind the permanent change and extension both in space and time.



Example application: Hotel on the Moon. The guest's aim: to stay in lunar environment in luxury conditions. It is a specific function of the hotel on the Moon to ensure for the guest to spend optional time with viewing the surroundings. A panorama platform, or a big tower for looking round is natural requirement. Atmosphere and safety air-lock systems are required for this.

Additional functional units of a hotel: 1) conditioning, fitness, wellness facilities, where movements under low gravity conditions can be experienced, 2) Eating function – eating under low gravity conditions, 3) Sleeping – relaxing, 4) Other internal services: playful movements, 5) Connecting with external stay: external and internal air-locks, multiply air-locking, with vehicle, personally.

Feasibility Study: At the beginning: the modules are made on the Earth, delivered to the Moon, and assembled there.. For example shell-like elements of the modular units (standardized). Later certain elements of the lunar base buildings can be made on the site as well. In other studies we showed that in order to make construction and operation of lunar buildings economical, they should be placed in subsurface environment. Therefore human settlements should be placed in natural depths: 1) ditches– linear and spatial extension, 2) crater – central and spatial extension, and there buried with lunar dust. These creations can be considered optimal from the point of view of every functional requirement.

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PLANNING PROJECT FOR ESTABLISHING BUILDINGS ON THE MOON TO BE OPERATED COST-EFFECTIVELY. B. Boldoghy[1], J. Kummert[1], Sz. Bérczi[2], T. Varga[3], I. Szilágyi[3], [1] Ferroelektric Engineering Pan Konceptum Ltd., H-1116 Budapest, Vasvirág sor 72., Hungary, (konceptum@vipmail.hu), [2]Eötvös University, H-1117 Budapest, Pázmány P. s. 1/a., Hungary (bercziszani@ludens.elte.hu), [23]VTPatent Agency, H-1111 Budapest, Bertalan L. u. 20., Hungary (info@vtpatent.hu),

Summary: The main steps of the planning program: 1) determining the aims and starting data, 2) determining what buildings are necessary to be built, 3) economic optimalization of the whole complex, 4) priorities and schedule of realization. The advantage of our program: highlighting certain tasks optimally from economic point of view.

Introduction: The aim of the proposal is: Compiling an architectural planning program, on the basis of experiences on the Earth, but taking into consideration the requirements of the lunar environment. These criteria select directions and principles to be applied for planning the architectural environment and buildings cost-effectively on the Moon.

Discussion: Preliminaries: Planning of buildings on the Earth is well known. For efficient planning method for objects (and their functions) we focus on certain objectives or advantage to be achieved in lunar conditions. Such objectives can be: 1) the protection of the environment, 2) finding the most cost-effective engineering solution, 3) taking into consideration special requirements, e.g. luxury, or special industrial activities, 4) ensuring economical operation, 5) ensuring optimal co-ordination of structural and operational conditions of the building.

In terrestrial planning procedure ubiquitous conditions can be taken into considerations. Such characteristics are: 1) atmosphere, unlimited availability of oxygen, 2) atmospheric pressure, 3) availability of water with the exception of special sites (e.g. desert, arid regions), 4) rate of gravity factor ($g = 9{,}81\ m/s^2$), 5) the existence of biological vegetation and organic load resulting from it. In non-terrestrial environments, however, the initial parameters are significantly different from those on the Earth.

Special characteristics on the Moon: 1) Lack of atmosphere, 2) Different temperatures and extreme values depending on irradiation, 3) Different gravity factor – 1/6 g, 4) Irradiation factors, cosmic radiation, direct presence of particle radiation, 5) Effect of micrometeorite hits, 6) Lack of water and any other liquids, 7) Complete lack of meteorological effects, 8) Different types of erosive effects. Other important lunar surface factors: 1) Surface rocks, 2) Surface relief conditions, ditches, craters, 3) Compactness of surface, rate of niggling, dust, 4) Floating micro-dust.

For operating cost-effectively a lunar building the main requirements are divided into several criteria: 1) Functional criteria: industrial premises, residence for human stay, premises for research and experiments, 2) Locational criteria: Which part of the Moon: poles, equator, seas, mountain chains, ranges, ditches, craters, 3) Engineering criteria: size, materials used, local fabrication or delivery, 4) Energetic criteria: energy requirement (in case of industrial activity it is increased). On basis of the above criteria we suggest as the main steps of a planning project as follows: I.) A) Clarifying initial conditions: function, site, raw materials. B) Exact assessment of conditions of the site: composition of the surface, relief. C) Rate of irradiations (Solar and inner heat flow, cosmic radiation). Next are the aspects of cost-effectiveness: II.) Preparation of preliminary engineering calculation: A) Assessment of resources, B) Assessment of transport possibilities and raw material purchase. III.) Optimalization: A) Working out the optimal proposals for the given conditions, B) Several alternatives, considering the structure of the building as well as conditions of cost-effectiveness, C) Possibility of using robots during realization of project, D) Granting priority to facilities that can be made with the use of robots, E) Feasibility study, financial cost calculations (evaluation of certain technical proposals from financial aspect: letting them compete). IV.) Opting for the best solutions both from technical and financial point of view.

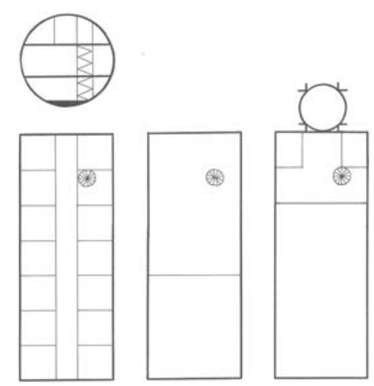


Fig. 1. Overview of a lunar habitation unit with 3 floors. From left to right: the upper level, (rooms, bathrooms) the middle level (kitchen and conditioning) and the lower level with communal store. Connection to node is from the lower floor.

Experimental type description: Let us see an example: a facility suitable for long-term housing for 8-10 people. The required functional units: entrance unit, community unit, dining unit, sleeping units, personal hygiene units, personal storing unit, training and fitness unit, changing unit, common store. The required spaces are the following: 1) Personal micro-space – separate bedroom unit for each person, 10 blocks for 10 people, 3-4 m^2/person; 2) Personal storing unit – suitable for the whole staff, 10 people, 30-40 m^2; 3) Community unit – suitable for the whole staff, 10 people, 30-40 m^2, 4) Dining unit - for half of the staff for one occasion - for 4 -5 people, 12 m^2 (The dining unit can be preferably part of the community unit) 5) Personal hygiene unit – for at least two, preferably for three people at the same time, 3 m^2/piece, 6) Training and fitness unit, for four people at the same time 30 m^2, 7) Entrance unit – directly from the corridor, in case of external space by airlock 8-10 m^2, 8) Changing unit – joining the entrance unit for external- internal dressing 30 m^2, 9) Common store – daily utilities, foods. As a sum cca. 200 m^2 is necessary to cover the above functions in case of long-term stay.

Certain functional units can be arranged above each other resulting in saving space. More complex settlement structures can be organized by joining such units. Working places, research sites, industrial activities are located in other modules.

LUNAR ENTREPRENEURS STUDENT COMPETITION. G. M. Cadenhead[1] and B. O. Fort[2], [1]MOOT CORP® Foundation and MOOT CORP® Pontoon Fund cadenheadg@mail.utexas.edu [2]Center for Space Research, University of Texas, 3925 W. Braker Lane Suite 200, Austin TX 78759-5316 fort@mail.utexas.edu

The Lunar Entrepreneurs Student Competition (Lunar Entrepreneurs) is a proposed new university competition, where competing teams of graduate students develop sophisticated and realistic business plans for commercial activities on the Moon. It would be modeled on and operate as a parallel track of the Moot Corp® Competition [1], applauded by *Inc. Magazine* as "The Rose Bowl of business-plan competitions." Like teams competing in Moot Corp®, Lunar Entrepreneurs student teams would vie for recognition, cash awards and, for the Grand Prize Recipient, $150,000 in start-up resources.

It is anticipated that, through Lunar Entrepreneurs, new opportunities would be identified for private investment in lunar exploration and development. New products or services proposed within the business plans are likely to include, among others, the mining and extraction of resources; the construction of scientific facilities; the use of lunar resources for construction, manufacturing, or power generation; novel uses of the lunar environment or location; and commercially-provided space transportation and power. Aerospace and lunar science community professionals are to be recruited to serve as either (partial) mentors or (impartial) technical resources for the competing student teams, providing advice regarding the types of products and services that could be produced or offered on the Moon (e.g. tourism, materials production, energy, communications).

Lunar Entrepreneurs is also expected to bring about (a) a commercial sector more deeply engaged in activities supporting NASA's exploration roadmaps; (b) a high-visibility, annual conference at which student teams will present their work to interested NASA, industry and university community professionals; (c) an expanded constituency for lunar development activities within non-traditional professions and academic disciplines such as business, public administration, and public affairs, as well as within the general public; and, (d) a high-profile series of annual student competitions integrating the nation's vision for lunar exploration and development into the commercial marketplace.

Participants are to be graduate students enrolled in any discipline (not just MBA programs) in an accredited U.S. institution of higher education. Business plans would be prepared under faculty supervision; ideally, for course credit.

Within its proposed Business Plan, each Lunar Entrepreneurs team will be required to:

- Define a lunar-related product or service that could be commercialized;
- Determine relevant market characteristics (size, segmentation, etc.);
- Identify cost and price issues, risks, competitive products or services, and funding sources; and,
- Provide projected financial data, including (a) a cash flow, income, and balance sheet projections; and (b) an explanation of the offering to investors indicating how much money is required, how it will be used, and the proposed structure of the deal (i.e., stock, debentures, etc.).

Once selected, up to 30 Invited Teams would present their work at the Moot Corp® competition, which is held in May of each year. Their audience would include business and venture capital experts, as well as NASA technology, operations, and space product development experts.

Plans call for the recruitment of program partners to sponsor awards. The Grand Prize Recipient is to be awarded (a) $100,000 in the form of convertible debt, convertible into common stock based on the price of the venture's first venture capital investment; (b) $25,000 in accommodations at the Austin Technology Incubator, in the form of legal and accounting services, discounts on Dell products, access to venture capital expertise, office space (if relocates to Austin, Texas) and other support; and, (c) $25,000 worth of legal services for the prosecution of the team's first American patent.

Other awards would go to the Runner-Up Team ($2,000) and four Semi-Finals Winners ($1,000 each). These amounts are identical to the awards granted to the winners of the Moot Corp® competition, ensuring that Lunar Entrepreneurs will attract the attention of the nation's best student talent.

Highlights and film footage of the Lunar Entrepreneurs student presentations will be web-streamed to over 100,000 current MBA and business students from all over the world through WWW.MOOTCORPtv.COM. As a featured MOOTCORPtv site, Lunar Entrepreneurs will be positioned to directly communicate globally with business students and positively promote NASA's entrepreneurial support initiatives.

References:

[1] http://www.mootcorp.org

A Demonstration of Vacuum Pyrolysis. E. H. Cardiff[1], B. R. Pomeroy[1], and J. P. Matchett[2], [1]NASA Goddard Space Flight Center, [2]United States Air Force.

Introduction: The in-situ production of oxygen on the lunar surface is a key part of our future in-space propulsion infrastructure. Over 20 separate technologies have been identified as being capable of producing oxygen on the lunar surface. Taylor et al. concluded from a review of available technologies that the optimal technique to produce lunar oxygen is the vacuum pyrolysis technique[1]. However, very little research has been performed to develop this technique, with most research and development efforts focusing on reduction techniques.

Experiment: Preliminary work has been performed at NASA Goddard Space Flight Center (GSFC) to advance the readiness level of the vacuum pyrolysis technique. The technique is theoretically very simple. Lunar regolith is placed into a reactor that is heated to ~2500 Celsius by the native solar flux. The material vaporizes, and as part of this vaporization process, the highly oxidized lunar regolith is reduced and oxygen is formed. The reduced oxides are condensed out and discarded, and the gaseous oxygen is pulled out of the chamber. A picture of the prototype system developed to test vacuum pyrolysis is shown in Figure 1. The initial prototype was very similar to the work by Senior [2]. Two different solar concentrator concepts have been developed to heat the regolith: a large parabolic reflector, and a large Fresnel lens.

Figure 1. The prototype setup with the Fresnel lens.

Results: Several different lunar "simulant" materials have been vaporized and condensed, including ilmenite, enstatite, and MLS 1a. Masses of approximately one net gram of material have been vaporized with the small prototype system. Preliminary testing of the condensation system shows that the condensation will occur within a few centimeters of the crucible. Scanning Electron Microscope (SEM) tests of the slag have shown reduced oxygen at the surface of the remaining sample, indicating that there is a net oxygen production. An example of a SEM image from early testing is shown in Figure 2. Modeling of the process predicts oxygen yields of between 11 and 20%, depending on the feedstock.

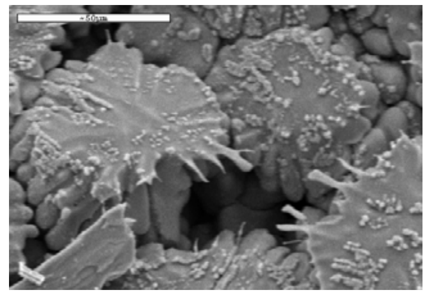


Figure 2. Scanning Electron Microscope (SEM) picture of ilmenite from the chamber. The surface of the crystals has been melted and vaporized.

Several problems were encountered as part of operations. The prototype system has been operated at pressure down to 10^{-3} Torr. The addition of a turbopump to lower this pressure will allow a mass spectrometer to be operated directly in the flow to measure the presence of oxygen. It will also reduce the vaporization temperature, and will more closely mimic lunar conditions. The windows for the chamber were also sensitive to thermal shock, vapor deposition, and thermal expansion. Window failures limited the durations of the tests to less than one hour. A combination of techniques have been tried and will be used to solve the problem of window failures, including a secondary window between the crucible and the vacuum window, increased distance between the sample and the window, and thicker replaceable vacuum windows.

Conclusion: The vacuum pyrolysis technique has been demonstrated with relevant lunar simulants, and shown to produce oxygen. The completion of a larger flux system, a lower gas pressure in the system, and more rugged windows will allow larger samples to be vaporized and to prepare for a flight experiment.

References: [1] L. A. Taylor & W. D. Carrier, III., Oxygen Production on the Moon: An Overview and Evaluation, Resources of Near Earth Space, (1993). [2] C. L. Senior. (1991) *JBIS., 44,* pp.579-588.

DEVELOPMENT OF STANDARDIZED LUNAR REGOLITH SIMULANT MATERIALS. P. Carpenter[1], L. Sibille[1], and S. Wilson[2], [1]XD42/BAE Systems, Marshall Space Flight Center, AL 35812, paul.carpenter@msfc.nasa.gov, [2]United States Geological Survey, MS964, Lakewood CO 80025.

Introduction: Lunar exploration activities require scientific and engineering studies that use standardized testing procedures and ultimately support flight certification of hardware and the development of technologies for their use on the lunar surface. It is necessary to anticipate the full range of source materials and environmental constraints that are expected on the Moon and Mars, and to evaluate in-situ resource utilization (ISRU) coupled with testing and development. Historical use of lunar simulants has focused on physical aspects of the lunar regolith for landing and transportation activities. Lunar mare simulants MLS-1 and JSC-1 have been developed, but supplies have been exhausted. Renewed emphasis on exploration and ISRU activities requires development of standardized simulant reference materials that are traceable interlaboratory standards for testing and simulate the lunar regolith in terms of physical, chemical, and mineralogical properties. This new generation of lunar regolith simulants must therefore support both technological development and testing methods. These issues were extensively discussed at the 2005 Lunar Regolith Simulant Materials Workshop [1].

Root and Derivative Lunar Simulants: A lunar simulant is manufactured from terrestrial components for the purpose of simulating one or more physical and chemical properties of the lunar regolith. A *root* simulant represents an end-member in terms of simulant properties, and a *derivative* simulant is formed from a root by modification or addition of material [2]. The degree of duplication of soil characteristics in the simulant is the simulant *fidelity*. The 2005 Workshop recommended production of two root simulants corresponding to a low-Ti mare basalt and a high-Ca highland anorthosite. These roots represent compositional end-members of mare and highland materials, and can in principle be physically mixed to target the range of soil compositions in the Apollo inventory. Specific lunar regolith properties can be addressed by addition of ilmenite, glassy agglutinates, nanophase iron, and other materials [3]. The fidelity of root simulants is thus increased by addition to form derivative simulants. Lunar dust simulants are also needed for studies on human toxicology and mechanical abrasion. The workshop recommended redeployment of JSC-1, as it can serve as a preliminary general purpose testing material for immediate needs while root simulants are developed.

Standardized Simulant Reference Materials: An ideal standard reference material is homogeneous, widely available, and inexpensive to produce and purchase. Homogeneity is most important, on the scale of material supplied to the end user, and on the scale of a production run. Geochemical standards are finely-ground rock powders that reduce chemical variability by reducing the grain size. Small aliquots of the standard are representative of the master distribution because each aliquot contains a large number of grains. Conversely, lunar simulants have a grain size variation and distinct modal mineralogy at each size fraction that must be retained in order to match the target lunar regolith. As the sample size is reduced, at some point it is no longer representative. The deviation in properties is typically monitored by chemical analysis using major, minor, and trace element analytical data of progressively smaller sample sizes, and comparing these data with replicate analyses performed on bulk material. This problem is illustrated for MLS-1, where a ~10% variation in SiO_2 is observed, compared to a 160% variation for Cr. This is a chemical contrast effect, illustrating small differences in the major element Si for silicates, but large differences for the trace element Cr. Similarly, geotechnical properties may be dominated by a large difference in mineral hardness, and rogue grains would stand out in tests using too small a quantity of material. The variability of simulant material thus is an inherent property but must be taken into account for both quality control and for simulant use by the scientific community.

Simulant Production and Quality Control: Simulant production requires selection of the appropriate terrestrial source material, milling to produce the required grain size distribution, characterization of chemistry, mineralogy, and geotechnical properties, and monitoring of adherence to simulant requirements and homogeneity during production. Simulant must be characterized during critical stages of production and packaging. This quality control establishes a traceability and a chain of calibration to a master set of reference standards. A supplied certificate documents the placement of the simulant material within the production sequence, and includes compositional data and other information specific to the reference material.

References: [1] Sibille L. and Carpenter P. (2005) *Lunar Regolith Simulant Materials Workshop Final Report and Subsequent Findings*. NASA Technical Memorandum (*In preparation*). [2] Carter J., et al. (2004) Space Resources Roundtable VI, 15. [3] Taylor L. et al. (2004) Space Resources Roundtable VI, 46.

SUSTAINABLE HUMAN PROSPERITY: EARTH, MOON, & BEYOND

David R. Criswell, University of Houston, Institute for Space Systems Operations, Houston, TX 77204-5006 713-743-9135, 281-486-5019, dcriswell@uh.edu or dcrsiwell@houston.rr.com

Introduction: The lunar surface intercepts ~1,000 times more solar power than the commercial output of all terrestrial power plants. The Lunar Solar Power (LSP) System can capture a few percent of the solar power and dependably deliver it as electric power to grids on Earth (Figure 1). A government-funded LSP demonstration will enable industrial development of the Moon, sustainable economic prosperity on the Earth and the Moon, and industrial-scale exploration of the Moon and Solar System.

Sustainable Lunar Development: The United States is committed to establishing a sustainable base on the Moon [1]. The base can use lunar materials to construct the demonstration LSP System depicted in Figure 1 [2, 3]. The program will establish Earth-Moon transportation, lunar habitats and workshops [#6] for tens of people, production systems [#4, #5], and power plots composed of lunar-derived components [#1, #2, #3]. These activities will rapidly advance knowledge of the Moon and solar system, human health and safety, understanding of human/machine industrial processes, and enable the entry of private industry and capital.

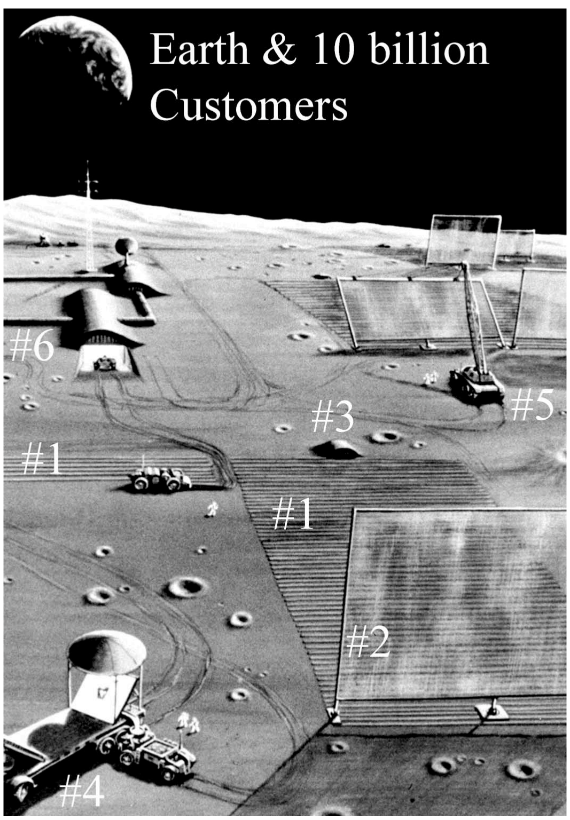


Figure 1: LSP Demo Base: Multiple Power Plots (Arrays of Solar Converters #1, Microwave Transmitter #2, and Microwave Reflector #3), Set of Mobile Factories (#4) & Assembly Units (#5), and Habitat/Manufacturing Facility (#6)

Private Sector: Since 1980, electric energy has increased gross world product at 26 T$/TWe-y. GWP can increase from 44 T$/y to 250 T$/y by enabling everyone on Earth to consume as much electricity as U.S. citizens now consume [4]. The economic return will attract private capital and the Moon will become a permanent part of the sustainable human economy and establish a growing human economy on the Moon.

Industrial-Scale Lunar RTD&E: LSP deployment will enable large research facilities and hundreds of researchers [4]. Initial lunar research, technology, development, and engineering can focus on the resources and processes that will significantly reduce the scale and cost of the LSP Demo (Figure 1: #1 – 6) and generalize lunar industries.

Beyond the Moon: LSP facilities and revenue will enable very large radio and optical observatories, lunar-scale active plasma experiments, beam-powered vessels to the other planets and to asteroids and comets. Lunar industrial and habitat units can be adapted to near-Earth objects and to Mars and its moons. These long-term space facilities can be sufficiently large to provide adequate shielding against cosmic rays and can rotate to provide artificial gravity.

References: [1] Bush, President G. W. (2004, Jan. 14). [2] Criswell D. R. (2002) Energy prosperity within the 21st Century and beyond: options and the unique roles of the sun and the moon, *Innovative Energy Solutions to CO_2 Stabilization* (Ed. – R. Watts), Ch. 9, Cambridge Un. Press. [3] Criswell D. R. (2001) Lunar Solar Power System: industrial research, development, and demonstration, 18th World Energy Congress. At http://www.wec.co.uk/wec-geis. [4] Criswell D. R. (2005) From Taxes to Profits, ms. 22pp. (available on request).
David R. Criswell copyright 2005

MISSION VISUALIZATION FOR PRECURSOR LUNAR TELEROBOTIC BASE PREPARATION. B. Damer[1] D. Rasmussen[1], P. Newman[1], B. Blair[2], T. Cochrane[3], J. Kohut[3] , J. Head[3], [1]DigitalSpace (343 Soquel Ave, #70, Santa Cruz CA 95062, bdamer@digitalspace.com), [2]Colorado School of Mines, [3]Raytheon, NASA ARC.

Introduction: NASA's return to the Moon by 2020 calls for sustainable human presence, suggesting that crew will make use of local resources for mission consumables. Generally referred to as In Situ Resource Utilization (ISRU), lunar regolith may be mined for small scale production of hydrogen, oxygen, water and volatiles. Proving up the capability to engage in ISRU will involve robot prospecting followed by infrastructure setup prior to human crews' arrival. In 2003, Raytheon was awarded a Concept Engineering and Refinement (CE&R) project by NASA to develop a lunar architecture trade study. Raytheon commissioned DigitalSpace to produce a vision for the telerobotic precursor preparation of an ISRU lunar base. Drawing from sources including Peter Eckart's Lunar Base Handbook [1] and early 1990s NASA outer planet exploration studies and other sources we produced a complete end-to-end mission scenario in real-time 3D for distribution to evaluators via the Internet [2].

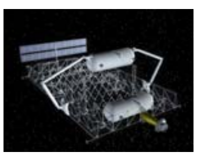
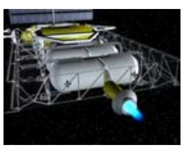


Figure 1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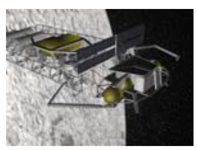
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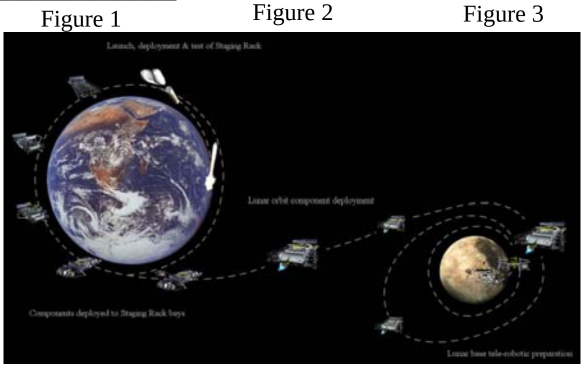

Figure 4

Results: Figure 1 above illustrates the resultant "rack" concept for an unmanned, teleoperated staging structure to be loaded in low Earth orbit with fuel, surface exploration and ISRU/construction robotics and sent to low Lunar orbit using ion propulsion (figures 2-4). Once there, the various robotic elements and human pressurized habitat are deployed and operated telerobotically from Earth. Figure 5 shows the deployment of a sinterer-excavator conceived of by Taylor et al [3] which heats and fuses the lunar surface to create a dust-mitigating stable surface for landing and trackways. The vehicle also buries the habitat for radiation protection. (figures 5-6). Teleoperated water ice/volatiles ISRU processing equipment then produces a full complement of mission consumables prior to the arrival of first crew (figure 7).


Figure 5

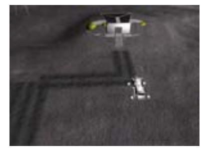
Figure 6

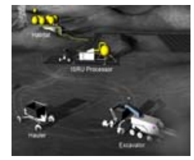
Figure 7

Conclusion: Advantages of this lunar telerobotic "rack" approach include:

1. If a single qualified ISRU source is found then this is an effective method to concentrate telerobotic resources for base preparation and ISRU utilization.
2. Single, low thrust rack delivery precludes use of multiple heavy lift launches directly to Moon and large savings in cost.
3. Rack remains in low Lunar orbit as a staging area with backup fuel and power for arrival of human crew and parking area for emergency return and on-orbit vehicles.

Risks assumed by this approach include:

4. Failure of any one element in the rack can lead to need to directly launch replacement element.
5. Radiation exposure of rack elements in Van Allen belts will last several weeks on slow trajectory.
6. Failure of rack itself will result in loss of all hardware.
7. Approach requires high readiness level in all aspects of teleoperation.

Call for Participation: DigitalSpace is calling for participation by LEAG, Space Resources Roundtable and the LPI communities to participate in future trades of this nature.

References: [1] Eckart, P. (editor), The Lunar Base Handbook, McGraw-Hill, 1999. [2] Find this mission visualization at: http://www.digitalspace.com [3] Taylor, L.A. and Meak, T.T., 2005, Microwave sintering of lunar soil: Properties, theory, and practice, J. Aerospace Engr., 18(3), 188-196.

DESIGN SIMULATION OF LUNAR EXPLORATION AND ISRU PROTOTYPE VEHICLES AND MISSION SCENARIOS. B. Damer[1] D. Rasmussen[1], P. Newman[1], B. Blair[2], M. Duke[2], R. King[2], T. Muff[2], M. Shirley[3], W.-M. Shen[4], [1]DigitalSpace (343 Soquel Ave, #70, Santa Cruz CA 95062, bdamer@digitalspace.com), [2]Colorado School of Mines, [3]NASA ARC, [4]ISI, University of Southern California.

Introduction: NASA's return to the Moon by 2020 calls for sustainable human presence, suggesting that crew will make use of local resources for mission consumables. Generally referred to as In Situ Resource Utilization (ISRU), lunar regolith may be mined for small scale production of hydrogen, oxygen, water and volatiles. The Colorado School of Mines constructed and tested a prototype Bucket Wheel Excavator (BWE) in 2003 (fig 1) [1]. This vehicle is an early prototype of a common mining vehicle adapted for lunar size and power. Under SBIR program support, DigitalSpace created a virtual model of this vehicle, placing it in a simplified simulated regolith environment to prove that a physics-based, force feedback joystick driven virtual vehicle simulation (figure 2) could be delivered to consumer personal computers via the internet.

Figure 1

Figure 2

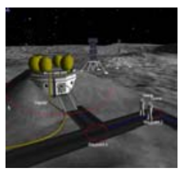

Figure 3

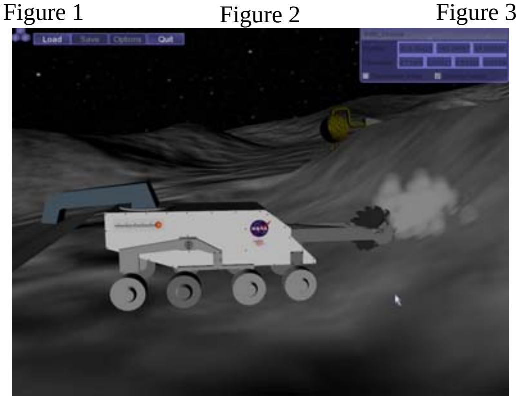

Figure 4

Results: DigitalSpace created a model of the vehicle drive train, bucket wheel operation, limited surface dynamics and dust behavior model (figure 4) and placed the vehicle in a lunar base/ISRU processor setting (figure 3). DigitalSpace is pursuing this work further by assembling a team of expert advisors and building a collaborative design platform to iterate a dozen or more lunar surface mission vehicles and scenarios. In the years 2006-2007 we plan to host regular telephone conference calls in which participants will operate design concept lunar vehicles and mission scenarios in synchronized real-time 3D environments. Participants will comment on the designs and this commentary will be used to iterate the virtual vehicles. During this period a parallel effort at Colorado School of Mines' "Project Dust" NASA H&RT research and development effort will create granular materials and dust behavioral simulations that will be used to create a medium fidelity virtual regolith sandbox for this effort.

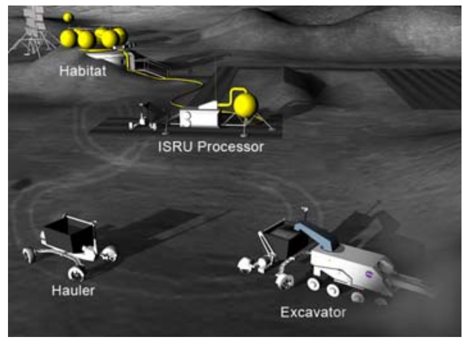

Figure 6

As the lunar robotics exploration program (LREP) is expected to create a roadmap for several types of surface missions it is hoped that this early prototyping effort will generate a number of viable designs for vehicles including:

1. Mobile platforms to explore permanently shadowed lunar Polar regions to test the hypothesis that water ice may be found there.
2. Drills to permit deeper exploration of loose aggregates or coring of stable regolith.
3. Excavator/processor vehicle designs for regolith handling and processing (figure 6).
4. "Superbots" style innovative robotics permitting one stationary lander to deploy smaller reconfigurable explorers [2].
5. Construction, inspection and maintenance telerobotics to provide base assembly and astronaut assistance on the lunar surface.

Call for Participation: DigitalSpace is calling for participation by LEAG, Space Resources Roundtable and the LPI communities to participate in this project.

References: [1] Muff, T., Johnson, L., King, R., Duke, M.B., A Prototype Bucket Wheel Excavator for the Moon, Mars and Phobos, Proceedings of STAIF-2004. [2] Taylor et al, this volume.

ISRUS INTEGRATED SPACE RESOURCES UTILITY SOFTWARE. J. Díaz[1], [1]Colorado Scool of Mines (jadiaz@mines.edu), [2]Affiliation for second author (full mailing address and e-mail address).

Abstract: In recent years Colorado School of Mines has focus in the analysis and design of the effect and benefits of ISRU in different space exploration scenarios. Although the models have been proven very useful, they are limited to the specific scenario they have been created for, and their interfaces are not user friendly. As a logical next step, CSM is developing an integrated tool which includes all CSM ISRU models and is easy to use and flexible. To allow for maximum flexibility, an Excel model with embedded Visual Basic code has been set up; this enables us to show the possible ISRU production capabilities and evaluate the effects of ISRU in different lunar & martian architectures, allowing the user to set up any desired architecture and easyly compare it with others with different ISRU use, schedules, transportation systems, payloads, etc. The effect of new and/or improved technologies and capabilities can be also tested. The analysis and comparison uses technical (IMLEO) and/or financial, (cost per year, NPV) metrics. Additional modules can be integrated in the future for evaluating commercial scenarios.

References: [1] Diaz, J. et al. (2005) JSC Space Transportation Architectures and Refueling for Lunar and Interplanetary Travel and Exploration report *(NAG9-1535).* [2] Duke, M.B. et al. (2003) Architecture Studies for Commercial Production of Propellants From the Lunar Poles *STAIF 2003.* [3] Lamassoure, E. et al. (2003) Evaluation of Private Sector Roles in Space Resource Development. *STAIF 2003.*[3] Blair, B. et al. (2002) Space Resource Economic Analysis Tookit: The Case for Commercial Lunar Ice Mining. *Final Report to the NASA Exploration Team.*

LUNAR RESOURCES CONSORTIUM: A PRIVATE/PUBLIC PARTNERSHIP IN SPACE RESOURCE DEVELOPMENT. M. B. Duke[1] and B. O. Fort[2], [1]Institute for Space Resources, Colorado School of Mines, 1500 Illinois St., Golden, CO 80401 mduke@mines.edu [2]Center for Space Research, University of Texas, 3925 W. Braker Lane Suite 200, Austin TX 78759-5316 fort@mail.utexas.edu

The development of space resources will reduce the cost of human exploration of the Moon and Mars, increase the scope and scale of human activities outside of the Earth, and provide a basis for new industries in space that return benefits to the Earth and eventually to human space colonists. The role of the government is to develop and demonstrate technologies by conducting missions of exploration. The role of industry is to support exploration and to develop commercial applications that provide broader economic benefits. Means are needed to start the engine of commerce in the context of government funded space exploration programs. This is difficult because, outside the aerospace industry, which is dependent on government space programs for its sustenance and is therefore not particularly innovative, knowledge of the potential for space industries is quite limited. Commercial investment in risky enterprises (the less information available, the riskier the enterprise will seem) is difficult and high rates of return to compensate for the risk are not apparent in space resource development. And government organizations, limited by public budgets, will generally not view the development program in its long term context, but aim to achieve short term demonstrations that are politically supportable. Government is not explicitly charged with supporting the development of new industry, although there are cases where governments do subsidize new industries where there is an apparent economic advantage for their country.

The semiconductor industry developed a consortium approach that has successfully impacted the industry through the formation of the Microelectronics and Computer Technology Corporation (MCC) and later Sematech. These organizations were created to allow corporations working in semiconductor development and production, which is a high cost and high risk technology industry, to pool resources where advancing the technology could serve the entire industry, while preserving the individual participants' proprietary competitive positions in the industry. Sematech now maintains a "global network of alliances with equipment and material suppliers, universities, research institutes, consortia, start-up companies, and government partners [1]."

Such an organization could serve the purpose of developing a space resources industry. The scope of the organization would include developing new processes, materials, and tools; studying the economic impacts of space resource development; providing assistance and information to entrepreneurs willing to invest in a long-term but potentially highly profitable new arena; and serving as a model and stimulator of public/private partnerships in space exploration and development.

A step in this direction has been the formation of the Lunar Commerce Executive Roundtable, a collaborator in this Space Resources Roundtable/LEAG Conference. Additional progress should be made in the coming year. It is important to do so because: (1) space resource utilization is becoming firmly implanted in the concepts for the NASA program of human space exploration; (2) early lunar resource utilization provides greater benefits than waiting until later; and (3) the incorporation of commercial development into NASA's space exploration program could reduce some government cost burdens. The enterprise will still be commercially risky from the point of view of private investment, so a space resources consortium similar to Sematech can reduce the risk to individual companies and provide a means for NASA to leverage its funding in this area.

Specific goals for the next year include: (1) establishment of the basis for a *Lunar Resources Consortium*, inorder to determine whether the concept is viable and can be broadly supported; (2) development of a set of conceptual business plans that demonstrate the potential economic benefits of lunar resources, so that entrepreneurs from outside the typical group of aerospace industries can be informed about viable possibilities and their technical risks; (3) evaluating current lunar resource production research in terms of adequacy and potential dual use technologies, to strengthen near-term economic incentives; and (4) conducting a Lunar Entrepreneurs Program, a business school competition, to interest and excite entry-level business people in the potential of space development.

References:

[1] http://www.sematech.org/corporate/index.htm

Acknowledgment: This work has been supported by NASA's Innovative Partnership Program, Space Partnership Development Office, directed by Dr. Frank Schowengerdt, NASA Headquarters.

STANFORD ON THE MOON ALUMNI INITIATIVE, 2000-2015. Steve Durst
Space Age Publishing Company /Lunar Enterprise Corporation Hawaii and California, USA.

The 2005 Stanford University Homecoming Reunion weekend will mark 5 years since the 2000 launch of the Stanford on the Moon alumni initiative with a major, historic gathering on Campus, Friday, October 21.

The Stanford on the Moon 2005 Conference, with almost 100 pre-registrants three months before the event, will assess various possibilities for a Stanford presence on the Moon in 2010 and 2015 -- the 50th graduation anniversary of the initiative's founding class of 1965. Along with a resourceful and diverse Advisory Panel, and with faculty, students, administrators and friends, alumni from classes spanning 50 years will advance organizational and funding operations necessary for achieving the 2010 and 2015 established goals. Longer range 21st century opportunities for the Stanford Overseas Studies Program also will be acknowledged.

Projects for early consideration by the Advisory Panel involve lunar orbital, power, robotic, biolab, astrophysics, and geology research and science. For 2015, human lunar activity involving Biosphere and CELSS applications, and an alumni supported Lunar orbital swing-by Apollo 8 style are being discussed, as are spin-offs, benefits, consequences and interactions between Stanford on the Moon and other national, international and commercial space / lunar developments.

A unique fusion of space enterprise, space education and space advocacy, the Stanford on the Moon alumni initiative may offer private sector examples for the space community and catalyze similar organization initiatives as it works to engage the enthusiasm and resources of the students, faculty, administration, friends and the more than 100,000 living alumni that constitute the Stanford community.

Human-Machine Integration for Exploration Science and Operations: History, Levels of Integration, and Open Questions. D. B. Eppler, Science Applications International Corporation, Mail Code OZ, NASA-Johnson Space Center, NASA Road 1, Houston, TX 77058, dean.b.eppler1@jsc.nasa.gov.

Introduction: For the past decade, often under the disguise of "technology development", teams within NASA have been developing and testing technology necessary to conduct efficient, scientifically productive exploration on the Moon and planets. Several of these teams have come together annually near Flagstaff, AZ to test technology and approaches for exploration. These exercises, named "Desert Research and Technology Studies (Desert RATS) have tested a number of technologies for both manned and robotic exploration, including new EVA suits, voice commanding of robotic and manned rovers, EVA tools, and EVA informatics. However, the most important question to be considered, but not yet answered, is the level of integration between human and machine systems that will result into allow a high level of "exploration efficiency" with significant science data return, minimal operations overhead and reduced costs.

Historical Considerations: Few would argue that the Apollo expeditions to the Moon were among the top achievements of the 20th century. The Apollo "paradigm" of exploration consisted of robot precursor missions acquiring initial data on environmental and surface conditions, followed by human landings that expanded in scope as confidence grew. EVA crewmembers and robotic systems did not operate in concert as robotic systems due to lack of mobility by robots. Operational control of flights was extensive and involved a very deep "bench", with a team of "front room" controllers that monitored spacecraft and crew in real time, backed up by large "back rooms" of technical experts on spacecraft systems. Computer technology was in it's infancy, and the computing power carried on-board the spacecraft was limited to managing the nominal mission plus monitoring spacecraft systems for off-nominal parameters. Perhaps the best example of the quality of this integrated team was the response to the Apollo 13 accident, where ground teams worked tirelessly with an increasingly fatigued crew to pull a safe recovery of the crew out of an extremely difficult situation. The Space Shuttle Program has operated according to a similar paradigm. However, exigencies associated with operating a continuously operating spacecraft like the Mir and International Space Station has shown that this paradigm must undergo a significant shift in order to conduct safe, efficient and cost-effective exploration. In particular, the cost of maintaining standing full-time armies of personnel is untenable for a long-term planetary exploration program, and the use of the combined human and robotic team on a planet's surface is needed to increase real-time science return and reduce the operations overhead needed for planetary exploration.

Human-Machine Integration: The Desert RATS testing has suggested considerable synergy is achievable with a human/robotic rover partnership. Several "states" can be envisioned: complete independence, supervisory dependence and complete interdependence. As independent systems, robots can do the kind of repetitive data-gathering or deployment tasks necessary to developing operations plans or acquiring planet-wide environmental and geophysical data, leaving humans to analyze the resultant data and investigate specific, integrated problems identified by robots. In the case of supervisory dependence, robots can be controlled by humans, either in EVA suits or in pressurized enclosures, to investigate locations and situations in relatively close proximity that, for reasons of either risk or biological contamination, require humans to "stand-off" from the area of interest. Complete interdependence would occur when a suited crewmember interacts directly with a robot, as a field assistant, tool carrier, analytical agent or, in dire cases, rescuer. Desert RATS testing has shown that integration of EVA crewmembers into the command/control loop for rovers can improve the efficiency of rover operations, particularly where EVA exploration sites may 10-20 km away from a habitat site.

Open Questions: Many questions have been raised by the Desert RATS activity, including: 1) "job" breakdown between human and robotic explorers; 2) delivery systems and quantity of command/control information to the EVA crew; 3) size and level of oversight by ground operations teams; 4) efficacy and efficiency of intelligent software for mission planning and control for replacing large operations teams; 5) efficacy and efficiency of voice-actuated controls for EVA crew; 6) identification and location of geochemical analytical assets on planetary surfaces, particularly whether those should be EVA tools or left in the habitat; 7) efficacy and efficiency of mixing the capabilities of robotic rovers with manned transport rovers; 8) degree of autonomy and "self-driving" capability for manned rovers; 9) location for the most efficient control of robotic rovers. Significant efforts should be expended to answer these questions as we move toward a reinvigorated human exploration program.

ESA'S SMART-1 MISSION: FIRST RESULTS AT THE MOON, STATUS AND NEXT STEPS

B.H. Foing[1], G.D. Racca[2], M. Grande, J. Huovelin, J.-L. Josset, H.U. Keller, A. Nathues, A. Malkki, D. Heather, D. Koschny, M. Almeida, D. Frew, R. Lumb, J.Volp, J. Zender, O. Camino, SMART-1 Science &Technology Working Team , [1]Chief Scientist, ESA, ESTEC/SCI-S, Bernard.Foing@esa.int, [2] SMART-1 ESTEC/SCI-S, postbus 299, 2200 AG Noordwijk, NL, Europe

Introduction: We shall report at SRR-LEAG 2005 the status from SMART-1 spacecraft and its instruments. Some first data and results obtained at the Moon will be presented, as well as perspectives for the extension phase and the preparation for future lunar missions. SMART-1 is the first in the programme of ESA's Small Missions for Advanced Research and Technology [1,2,3]. Its first objective has been achieved to demonstrate Solar Electric Primary Propulsion (SEP) for future Cornerstones (such as Bepi-Colombo) and to test new technologies for spacecraft and instruments. The spacecraft has been launched on 27 Sept. 2003, as an Ariane-5 auxiliary passenger and injected in GTO Geostationary Tranfer Orbit. Thanks to the successful electric propulsion navigation, the spacecraft has left the inner radiation belts in early 2004, reached lunar capture on 17 November 2004, and lunar science orbit in March 2005. The SMART-1 mission has spiraled down to reach a lunar orbit 300-3000 km for a nominal science period of six months, and extension until August 2006.

Overview of SMART-1 payload: SMART-1 science payload, with a total mass of some 19 kg, features many innovative instruments and advanced technologies [1]. A miniaturised high-resolution camera (AMIE) for lunar surface imaging, a near-infrared point-spectrometer (SIR) for lunar mineralogy investigation, and a very compact X-ray spectrometer (D-CIXS) with a new type of detector and micro-collimator which will provide fluorescence spectroscopy and imagery of the Moon's surface elemental composition. The payload also includes an experiment (KaTE) aimed at demonstrating deep-space telemetry and telecommand communications in the X and Ka-bands, a radio-science experiment (RSIS), a deep space optical link (Laser-Link Experiment), using the ESA Optical Ground station in Tenerife, and the validation of a system of autonomous navigation (OBAN) based on image processing.

Electric propulsion and plasma instruments: The monitoring of the spacecraft plasma environment and the contamination produced by the Stationary Plasma thruster has been a key-task, carried out by two experiments: SPEDE (Spacecraft Potential, Electron and Dust Experiment, PI. A. Malkki) and EPDP (Electric propulsion diagnostic Package, PI G. Noci).

SMART-1 overall planetary science: SMART-1 science investigations include studies of the chemical composition of the Moon, of geophysical processes (volcanism, tectonics, cratering, erosion, deposition of ices and volatiles) for comparative planetology, and high resolution studies in preparation for future steps of lunar exploration. The mission could address several topics such as the accretional processes that led to the formation of rocky planets, and the origin and evolution of the Earth-Moon system [8].

SMART-1 operations and coordination: The Experiments are run during distinct phases of the SMART-1 mission: 1) the 17-months long Earth escape phase when the spacecraft spiralled out from Earth to perform a weak capture of the Moon on 17 November 2004; 2) a spiral down towards the Moon until March 2005 (but allowing some lunar observations); 3) a nominal science phase of 6-months and reboost of orbit; 4) an approved 1 yr extension in elliptical Moon orbit (starting at 400-3000 km) with pericentre near the south pole. The planning and coordination of the Technology and science experiments operations is carried out at ESA/ESTEC (SMART-1 STOC). The SMART-1 STOC supports also the mission data archiving based on the PDS (Planetary Data System) Standard.

The SMART-1 observations will be coordinated with upcoming missions. SMART-1 will be useful in the preparation of Lunar-A, Selene, the Indian lunar mission Chandrayaan-1, Chinese Chang'E , the US Lunar Reconnaissance Orbiter, and future lunar sample return missions. SMART-1 can also contribute to prepare the next steps for exploration: survey of resources, search for ice, monitoring polar illumination, and mapping of sites for potential landings, international robotic villages and for future human activities and lunar bases.

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Links: http://sci.esa.int/smart-1/, http://sci.esa.int/ilewg/

ECONOMIC DEVICE SYSTEM FOR EXTRACTING THE DUST AND AEROSOLS FROM THE ATMOSPHERE OF THE PERMANENT LUNAR OR MARTIAN BUILDINGS. T. Földi[1], Sz. Bérczi[2] [1]FOELDIX, H-1117 Budapest, Irinyi J. u. 36/b. Hungary, [2]Eötvös University, Institute of Physics, Cosmic Materials Space Research Gr. H-1117 Budapest, Pázmány P. s. 1/a, Hungary, (bercziszani@ludens.elte.hu)

Summary: Any movement activities amplify the natural levitating dust during the lunar days and generate dust in the Martian atmospheric conditions. For permanent planetary bases we propose an economic device, arrangement solution for the dust extraction by a dust-coagulator type instrument system arranged locally and working without moving parts.

Introduction: Measurements of the Surveyor landers and Apollo 17 LEAM experiments indicated a levitating lunar dust cloud above the lunar surface [1-3]. This ionized dust cloud is generated mainly by solar UV radiation [4]. Recently MER rovers on site observed dust devils frequently appearing in the Martian environment [5]. Dust devils transport dust locally, dust storms distribute and move dust globally. In the MPF and MER missions the continuous sedimentation of the fine Martian dust were also observed [6]. Both lunar and Martian permanent bases need solution for the continuous dust transport, because the presence of planetary dust is obstructive for measurements inside the lunar base.

Experiment: Earlier we studied the formation of the levitating lunar dust [7] which forms a transient quasiatmosphere in the lunar environment [8]. We modeled the electrostatic mechanisms of the lunar (and planetary) dust in our experimental arrangement and we concluded that charged dust particles can coagulate if they are charging with + and – charges alternates. Not only receiving but loosing charges helped the coagulation of aerosol particles. We found that if dust particles cover a longer interval in this alternating charging process then the electrostatically charged dust particles may form larger and larger grains. The coagulating grains may also attract and include H_2O molecules. The process of coagulation can be promoted by very small additional H_2O molecules, which help growing larger the dust clusters [8].

Instrument: As a consequence of the recognitions of the electrostatic charging and coagulation process we suggest a device system for permanent dust-extracting from the air of the lunar/Martian base. The coagulating process can be built into a collector chamber which not only extracts and coagulates dust particles but also keep in motion the atmosphere inside the lunar base without moving machine parts. A chamber with 2000 X 1000 X 250 millimeters volume (1 bar) and two systems of electrodes were arranged in the chamber, and were operated on + 15 kV and - 15 kV potential, respectively (the power supply was varied between 8 kV to 15 kV). Opened to the free air, the gas began to move through the instrument, by getting constant velocity of 1 meter/s [9].

Experiment with the instrument: We studied the production of coagulated dust particles in an electrostatic experiment [8-9]. In this work we used a chamber in the column-arrangement of the instrument - open up and down - on the bottom of the tube the coagulated particles dropped. They had quasi-spherulitic form and getting through 20 electrodes the maximal mass of the coagulated particles was 540.000. times that of the initial molecular mass [9, 10]. We observed that the addition (evaporation) of negatively charged water molecule-ions to the atmosphere the coagulated particles can grow larger. Water molecules help coagulation because they are small negative ions and have far longer lifetime then that of the small positive ions [8, 10].

Laboratory measurements of effectivity: The device was tested between two isolated rooms, which were connected through only a window, where the dust coagulator FOELDIX device was placed with airflow insulation (to exclude the air transport outside of the instrument). In Room-1 standard bacteria aerosol injector polluted the room by a given amount of bacteria. The concentration of the pollution was measured by nutrients placed in Petrie-dishes, in Room-2. The experiment was repeated with various bacteria. The effectivity of the bacteria filtering of FOELDIX was better then 0.99 [11].

Benefits of the aerosol coagulator device: Recent terrestrial solutions for dust extracting in a building works with centralized system. Instead of it our proposal for lunar/Martian base rooms a distributed unit system is used with local air cleaner units. The centralized system has ca. 20-50 times larger mass and 10 times larger energy request as compared our proposed distributed cleaner units system.

Conclusion: The dust-coagulating FOELDIX device system effectively collects the dust and other aerosols down to the fine 1/100 micrometer size range in lunar/Martian bases.

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VOLCANOES IN ALPHONSUS CRATER: 3-D ANALYSIS OF A FUTURE LUNAR LANDING SITE.

L.R. Gaddis, J.A. Skinner, Jr., L. Keszthelyi, T. M. Hare, E. Howington-Kraus, and M. Rosiek, Astrogeology Team, U. S. Geological Survey, 2255 North Gemini Drive, Flagstaff, AZ 86001 (lgaddis@usgs.gov).

Introduction: Alphonsus crater (~13ºS/357ºE; 108-km dia.) was considered as a possible landing site for Apollo 16 and 17. This crater will likely be of interest as a future lunar landing site because of the series of volcanic, dark-halo craters located along fractures in the crater floor. These volcanic deposits are thought to contain juvenile magmatic components [1-4], possibly olivine-rich, that may represent primitive lunar materials. We have created a new, high-resolution digital elevation model (DEM) of the crater floor to perform regional terrain analysis and to refine morphometric characterization of these volcanic deposits.

Data: We used digital reproductions and analysis of previous topographic data [5] as well as photogrammetric processing of Apollo metric and Lunar Orbiter photographs [6-7] to derive a 25 m/pixel DEM of Alphonsus crater (**Figures 1, 2**). Clementine UVVIS and NIR color data allow us to map the spatial extent of the volcanic deposits.

Results: Analyses of these data in a GIS environment result in a 3-D characterization of the region that can be used to constrain local terrain and constrain deposit volumes. Results suggest that (1) the deposits are generally <1 km^3 in volume; (2) small-diameter craters show a 1:1 ratio of excavated to deposited material, indicating a simple redistribution of excavated material in an explosive emplacment process, with minimal juvenile volcanic material; and (3) the three, large-diameter, composite craters (Soraya, "R", and Ravi craters) are surrounded by deposits estimated to contain ~50 to 80% of juvenile magmatic material.

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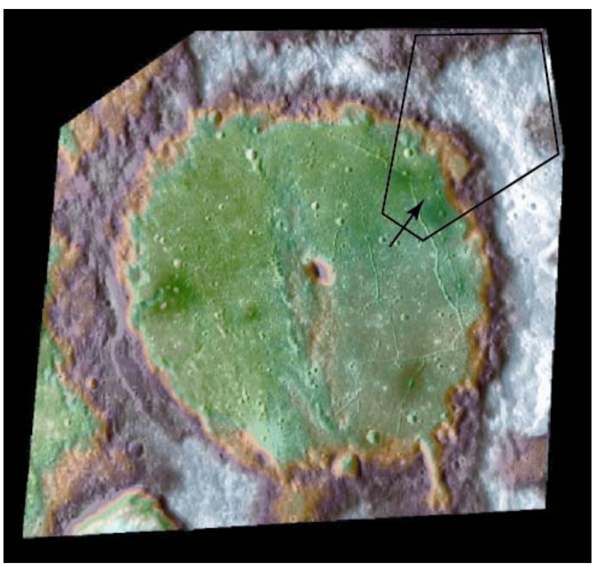

Figure 1. Apollo 16 stereo pair-derived DEM overlying Apollo 16 frame 2477. Extent and orientation of Fig. 2 3-D view indicated.

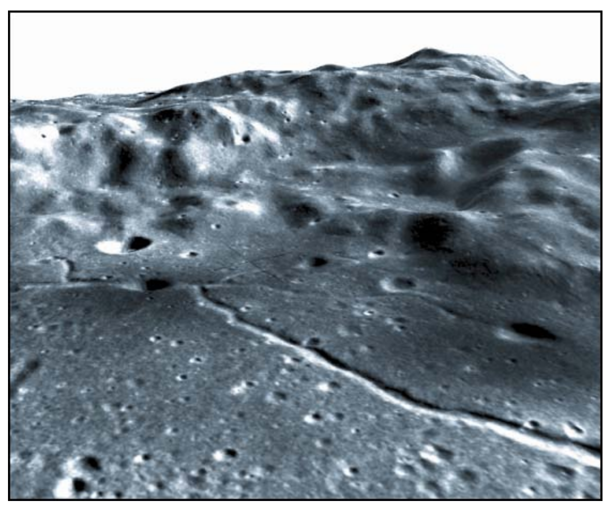

Figure 2. 3-D perspective view generated from ArcScene using Apollo 16 frame 2477 and Apollo 16 stereo pair-derived DEM. Note no vertical exaggeration.

MEETING NIGHTTIME POWER AND THERMAL REQUIREMENTS BY MANIPULATION OF THE LUNAR SURFACE ALBEDO AND EMISSIVITY. I. Garrick-Bethell, MIT Department of Earth, Atmospheric and Planetary Sciences, 54-520, 77 Massachusetts Avenue, Cambridge, MA 02129, iang@mt.edu.

Introduction: The manned scientific exploration of the Moon would benefit from missions that are not limited to their stay on the surface by 14 days of sunlight. Staying on the Moon for longer than 14 days is also important if the Moon is to be used as a hardware testbed for long-duration Mars expeditions. However, a problem with surviving the lunar night is the lack of solar energy for powering electronic equipment and heating a lunar habitat. Batteries charged during the lunar day could be used during the night, but their mass would be substantial. Nuclear fission reactors could provide power at any time, but these systems involve significant development, mass, and political issues. Energy storage devices such as flywheels have also been proposed, but of course their mass must still be brought to the lunar surface. Here I propose a scalable alternative means of energy storage that takes advantage of the material already on the lunar surface: the lunar regolith.

Solar energy in the soil: Below about 30 cm the lunar regolith maintains a relatively balmy ~250º K while the surface oscillates between ~110º and ~390º K at the equator (e.g. [1]). The constant subsurface temperature could be exploited for use in a "heat pump" that either cools or heats a habitat. Exchanging energy with the ground in this manner would be similar to the operation of underground geothermal heat pumps that are installed in the yards of homes on Earth. Additionally, electrical power could be derived from the temperature difference in the subsurface and materials on the surface either through a solid state Peltier-effect generator, or a turbine system. In both cases an energy exchange fluid would be run through the soil. However, a more workable scenario would probably require an increase in the subsurface temperature above 250º K. The lunar albedo is already quite low (~0.1), but the emissivity is rather high (>0.9). A review of some commercially available coatings and paints shows that some have emissivities of less than 0.1 and reflectivities lower than 0.1. If such materials could be applied to the lunar surface to create lower effective emissivities and low albedos, the lunar subsurface temperature could be raised to make heat pumps a more viable means of energy production.

Thermal model: A thermal model of the lunar soil is developed by solving the time dependent one-dimensional heat conduction equation. The model uses a two-layer regolith with thermophysical properties from [2], including a temperature dependent heat capacity and conductivity. The geothermal heat flux is ignored. For a reference model all calculations are for zero degrees latitude, with an effective emissivity of 0.1 and albedo of 0.1, and an initial temperature profile of 250º K down to 100 cm.

Results and Discussion: We find that after six years the subsurface temperature at 100 cm has increased to ~380º K, or roughly 1.8º K per lunar month. The slow growth of the temperature change presents a constraint on energy extraction, and suggests two possible modes of operation. One being to take as much energy from the regolith as desired (exploitative), and the other being to take only as much energy as can be restored by the sun during the lunar day (conservational). The success of either scenario will be dependent on the rate at which energy can be extracted out of the regolith, which itself depends on the geometry and thermophysical properties of the energy exchange apparatus (i.e. pipes and fluids). At any rate, to obtain some insight into the amount of energy available, ~1 kW of power can be provided for 14 days from a 2º K temperature decrease in 50 cm of regolith in a 40-m radius low emissivity region, assuming a joule-to-joule conversion efficiency of 15%. Generation of the "energy field" could be performed by rovers prior to arrival of any habitat and may require some 1000 kg of coating material.

Additional uses of altering the Moon's albedo:

High albedo daytime heat sink: For heat rejection during the lunar day, a colder subsurface heat sink could be created by increasing the albedo of the surface with a highly reflective coating.

Radiative heating: For very low emissivities and albedos, it may be possible to raise the minimum temperature of the regolith so that it radiates at a temperature that is high enough to contribute a radiative warming effect to any hardware nearby. A habitat or other hardware could be moved closer to the heat field late in the lunar night, and back out at dawn to avoid excess heating.

Conclusion: Among the methods of generating electrical and thermal energy at night, energy storage in the lunar regolith should be investigated as a highly scalable alternative process. Future work will address two dimensional heat conduction, and transport of energy out of the regolith.

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Human-Robotic Field Relations for the Moon: Lessons from Simulated Martian EVAs. W. B. Garry[1], W. J. Clancey[2], M. X. Sierhuis[2], J. S. Graham[3], R. L. Alena[2], J. Dowding[4], and A. Semple[1], [1]University at Buffalo, Dept. of Geology, 876 Natural Science Complex, Buffalo, NY 14260, brentgarry@yahoo.com, [2]NASA Ames Research Center, Intelligent Systems Division, MS269-3 Moffett Field, CA 94305, [3]NASA Johnson Space Center, S&K Technologies, Inc., Houston, TX 77058, [4]UC Santa Cruz, Moffett Field, CA 94305.

Introduction: Human-robot interactions during extravehicular activities (EVA) on the lunar surface will be important to the efficiency, productivity, and data return of the mission. In preparing for extended stays on the Moon, and eventually Mars, EVA tasks that can be easily automated need to be recognized and experience utilizing robots in the field must be gained. Over the last three years, our team has simulated several EVAs with two "astronaut-geologists" and an autonomous robot all utilizing an advanced, automated system called "Mobile Agents" (MA) with these necessities in mind. Inspired by the Apollo missions and designed for use during EVAs on Mars [1], the MA system monitors and manages EVA navigation, scheduling, equipment deployment, telemetry, health tracking, and data collection. A dialogue system [2] employs a series of voice commands (e.g. "*Move to location x*" and "*Take a panorama*") used by the astronauts to communicate and interact in real-time with their "agents" which are connected wirelessly through a complex relay system [3] to all participating members of the EVA (Astronauts, Robot, Habitat (Hab), Remote Science Team).

Field Tests: Our EVAs were carried out during 3 two-week field tests at the Mars Desert Research Station (MDRS) in Hanksville, Utah (2003-2005). The two "astronauts" and the EVA Robotic Assistant (ERA) (Figure 1) [4, 5], an advanced autonomous test bed robot from NASA JSC, followed various scenarios devised to test both technological and science objectives. A science backroom "on Earth" known as the Remote Science Team (RST) collaborated with the astronauts to plan EVAs and analyze data. Traverses covered up to 2 km and were conducted ≤8 km from the Hab while still maintaining full communication.

EVA Robotic Assistant: The ERA is an autonomous robot that can be programmed to follow a preselected path, controlled remotely from the habitat, or commanded on-the-go by astronauts in the field. The capabilities of the ERA include obstacle avoidance, video tracking, still imaging and 360° panoramic options, sample return and curation, and DGPS. We employed the ERA in the following roles during the EVA scenarios. **1) *Reconnaissance*** – solo-scouting of an unexplored location along a pre-set traverse. Astronauts monitored progress and data return from confines of the Hab and used it to plan the following days EVA with the help of the RST. **2) *Monitoring*** – Astronauts are automatically "tracked" by one of two video cameras located on the ERA. The video is broadcast back to the Hab for viewing by the Astronauts remaining behind. This job was performed manually from Mission Control during Apollo 15, 16, 17. **3) *Network Relay*** – While working in a canyon ~4 m deep, communication was maintained between the astronauts and the Hab by positioning the ERA in a strategic location along the canyon edge. **4) *Remote Workstation*** – A science trailer connected to the ERA increases both amount of field equipment and sample return for the astronauts.

Figure 1. Two astronaut-geologists and the ERA with science trailer prepare to leave the MDRS during a simulated EVA in the Utah desert. Image courtesy of NASA.

Application to Lunar Exploration: The EVA scenarios, roles of the ERA, and the MA system can be applied and utilized in Lunar EVAs. This includes reconnaissance of unknown terrain; monitor and relay capabilities while exploring craters or rilles; and instant automated downloading, cataloguing, and association of data for use by scientists back on Earth.

Websites: ERA and Field Tests (Crews 16, 29, 38)
http://vesuvius.jsc.nasa.gov/er_er/html/era/era.html
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SENSOR DEVELOPMENT FOR THE DETECTION AND CHARACTERIZATION OF LUNAR DUST. Paul S. Greenberg, NASA Glenn Research Center, Cleveland, OH 44135. Paul.S.Greenberg@nasa.gov.

Introduction: The presence of the particulate component of Lunar regolith (i.e. dust) presents numerous challenges to both robotic and human exploration. Effects associated with these materials were clearly observed in all surface missions associated with the Apollo program, and therefore represent a more significant concern for future missions of increased duration. The development of appropriate engineering solutions requires a more complete characterization of dust properties. Further, amenities for in-situ monitoring of particulates may be required to address human health and safety, as well as for insuring the reliability of associated support systems.

Requirements for particulate sensing: The experience provided by the Apollo Lunar missions demonstrated numerous problems associated with the particulate fraction of the Lunar regolith. This included the failure of mechanical components due to penetration and abrasion by dust, excessive wear on the exterior surfaces of the EVA suits, deterioration of the moving components in these suits, and even the failure in the vacuum seals of the sample return collection boxes. [1] Apollo 17 astronaut Harrison Schmidt proposed that the presence of dust represent the single largest technical impediment to future, long duration Lunar missions. [2] Evidence also suggests that the change in surface emissivity due to the accumulation and impregnation of dust noticeably altered the heat rejection attributes of electronic packaging provisions. More recent measurements for the Mars surface rovers also confirms the degradation in solar cell performance due to the surface accumulation of dust.

In terrestrial environments, the recognition of human respiratory health affects associated with fine particulates has increased dramatically over the past decade. [3] The potential for this concern in the context of Lunar environment is now widely recognized. [2] Of additional significance is the observed increase in toxicity of certain materials possessing reactive surface states. [4] Given the essential absence of a Lunar atmosphere and its associated radiation environment, the possibility for such states to be prevalent represents a problem worthy of consideration. Anecdotal evidence from the Apollo astronauts suggests that this aspect of Lunar particulates should be more systematically pursued. [2]

A more complete characterization of particulate properties is also significant from the perspective of ISRU processes. On one hand, the observed dependence of composition and structure with particulate size may promote specific strategies for targeting particular compounds of interest. [5] Viewed differently, the presence of particulates, with their high surface energies, may represent contaminants that need to me removed and monitored.

The features described above serve to motivate the need for a variety of sensors for particulate detection and characterization under a number of differing scenarios. For example, considerable gaps exist in our present understanding of the fine and ultrafine fractions of the Lunar regolith. In this regard, it is reasonable to suggest the development and deployment of sensors via robotic precursor missions. Specific parameters of critical concern to planetary exploration in the near term include a basic characterization of the particulate size and charge state distributions, as well as transport properties and surface reactivities.

Eventual human presence and surface operations will require the development of separate sensors for active monitoring and control. While provisions will be included for the filtration and abatement of particulates from habitation environments, sensors for monitoring the function of these systems to the appropriate levels will unquestionably be required. Similar statements apply to a variety of supporting surface systems whose reliability is potentially impacted by the exposure to or infusion of particulates.

Problem specific attributes: In the generic sense, the unique constraints of spaceflight applications cannot be accommodated by existing or conventional technologies. These typically include aspects such as size, volume, power consumption, and reliability. This is the case for particulate detection sensors relative to the present state-of-the-art. Desired reductions in overall package dimensions are particularly challenging, since the attendant reduction in throughput flux presents novel requirements for achieving the necessary detection sensitivity.

External to habitation or otherwise pressurized amenities, the 10^{-12} torr Lunar environment is further challenging. In this case, the adaptation and scaling of most existing measurement technologies is precluded. Methods predicated on exploiting stokes drag for size classification are at once ineffective, and conventional methods for artificially imposing electrostatic charge states are similarly disallowed. Common approaches to sample acquisition are generally inapplicable as well. All such features are being reconciled through a directed effort to design and demonstrate particulate sensors appropriate for this environment.

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PROCESSING OF LUNAR SIMULANT BY PARTIAL OXIDATION AND MAGMA ELECTROLYSIS.
D. L. Grimmett, Pratt & Whitney Rocketdyne, P.O. Box 7922, 6633 Canoga Avenue, Canoga Park, CA 91309.

Exploratory development work was performed to examine the feasibility of extraction of oxygen and iron or iron-rich materials from lunar simulant. Two potential routes were examined to produce useful materials from lunar soil. The first method involved high temperature electrolysis of molten magma for production of oxygen at the anode and a high iron material at the cathode. The second method involved partial oxidation of molten soil followed by cooling and magnetic separation of spinels or ferrite..

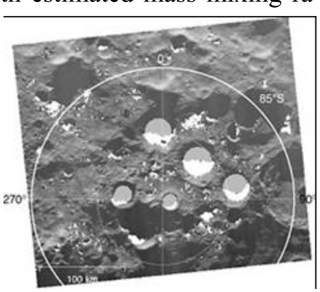
Electrolysis of molten magma at 1300C – 1400C under argon was carried out in alumina containers with kanthal or platinum electrodes. The electrolyte used consisted of a mixture of oxides or MLS-1 to simulate a high titanium basaltic material similar to Apollo-11 soil. Post electrolysis analysis indicated a high iron content electrolyte near the cathode with other areas partially depleted of iron. Cell design, electrolysis results and attempts at conductivity measurement are discussed.

Partial oxidation of molten lunar stimulant was carried out at 1400C with air. After partial oxidation, the molten material was cooled at various rates to yield a solidified material. The solidified material was ground and magnetically separated to an iron rich magnetic fraction and a nonmagnetic fraction. The magnetic portion was dissolved in sulfuric acid and electrolysis yielded metallic iron at the cathode with 98% current efficiency.

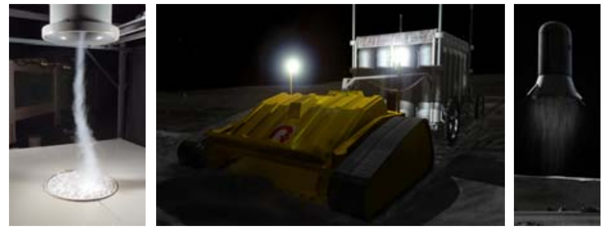
PRAGMATICS OF PROPELLANT PRODUCTION ON THE MOON. David Gump[1], William "Red" Whittaker[2], and Matthew E. DiGioia[2]. [1]Transformational Space Corporation LLC (11710 Plaza America Drive, Suite 2000, Reston, VA 20190, david.gump@transformspace.com), [2]The Robotics Institute, Carnegie Mellon University (5000 Forbes Avenue, Pittsburgh, PA 15213, red@cmu.edu and mdigioia@cs.cmu.edu).

From Ice to Propellant: Evidence of abundant ice motivates the technical and economic viability of effectively producing propellant from lunar volatiles. Lunar propellant production would vastly expand the opportunity for future exploration and possibly establish commercial enterprise. Near-surface ice concentration in lunar cold traps theoretically enables a straightforward approach to shallow surface excavation with volatiles extraction by heating and sublimation. This research examined the economics of lunar propellant production including baseline mission architecture and total equipment mass. Propellant production on the moon has a favorable rate of return on investment due to the minimal equipment mass that produces substantial propellant mass. On-going work will refine mission architecture including: defining techniques and mechanisms for volatiles extraction and capture by sublimation, characterizing mechanical and physical properties of icy regolith, and prototyping designs for robotic excavators.

Ice Awaits at the Lunar Poles: Lunar Prospector detected ice deposits, with estimated mass mixing ratios of 0.3%-1% [1], as close as ½ meter to the surface [2]. Water vapor could be driven from regolith by warming the regolith from about 50^0 K to about 150^0 K. Electrolysis of oxygen and hydrogen from concentrated water is well understood. LH and LOX can be liquefied with low confining pressure since the ambient temperature of a cold trap is cryogenic. LH and LOX can be combined to make propellant. Physical sublimation of ice for volatiles production may be vastly superior energetically and architecturally to chemical reduction schemes.



Simple Machines for Shallow Surface Excavation: The proposed scenario utilizes shallow surface excavation to accumulate batches of icy regolith. Depending on the mechanical properties of icy regolith, vehicles can load these batches without the logistical or technical complexities of deep digging. These robotic vehicles are analogous to terrestrial earth-moving scrapers, but would be miniaturized, lightened, reactor-powered, and specialized for extracting volatiles. Each excavator has a mass of 2,300 kg with a 20 minute cycle time to accumulate regolith, cover/heat to sublimate the ice, and deliver the resulting water vapor for electrolysis. An on-board thermionic reactor provides 130 kW thermal, for ice sublimation and to warm the machine from the cryogenic cold, and 10 kW electric (≈13 Horsepower) for mobility and operations. On-going work will expound upon this qualitative analysis with experiments to determine the best method for excavation of icy regolith with batch processing of volatiles.



Baseline Mission Analysis and Design: Preliminary mission architecture was developed estimating mass budgets, power required, and processing cycles to meet a propellant production yield of 255,000 kg per year. This propellant target constitutes fuel for two CEV's to be refueled on the moon's surface and return to Low Earth Orbit (LEO). Analysis shows that three trips of a cargo CEV would deliver 13,500 kg at a future Earth-to-orbit (ETO) propellant cost of $714 million, handily beating the present value target of $1.5 billion.

Conclusion: Robotic enterprise to mine lunar ice and produce propellant makes business sense and vastly expands the viability of future exploration. Propellants are producible with simple processes using simple machines. Physical sublimation is favorable to chemical reduction schemes, both energetically and architecturally. There are huge payoffs in discovering high ice concentrations. Small versatile scrapers could load, cook, and tow. Small reactors could provide electric power for scraper operations and thermal energy for sublimating ice.

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CAN MRI BE USED IN SPACE?: A RECENT DEVELOPMENT OF ULTRA LOW-FIELD MAGNETIC RESONANCE IMAGING SYSTEM. I. Hahn, K. Penanen, and B. Eom, Jet Propulsion Lab, Caltech, 4800 Oak Grove Dr., Pasadena, CA 91109, USA. E-MAIL: Inseob.Hahn@jpl.nasa.gov

Introduction: Conventional high-field MRI systems have been be used for diagnostics of human health for many years on the Earth. However, the current MRI system technology used in clinical applications is not suitable for space flight. This is mainly due to physical problems associated with a very large cryogenic dewar/cooler needed to operate a dangerously high-field superconducting magnet. We are currently developing a prototype MRI system that requires magnetic field comparable with Earth's field, which is many orders of magnitudes smaller than in the conventional MRI technique. The principle of the technique is based on the superconducting quantum interference device (SQUID), which was successfully used to measure small nuclear magnetism in both static and resonance conditions [1][2]. Recently, a detection scheme using the SQUID sensor has been successfully applied to construct a low field MRI system and to image biological objects [3]. The low field MRI technology also demonstrated a unique imaging capability of biological tissues, that is not feasible in the conventional high-field MRI system [4]. The imaging capability at ultra low fields eliminates the necessity of a large/bulky magnet, thereby creating an opportunity to develop a MRI system for space use. Moreover, recent low power cryocooler technology developed for astronomy missions can be used to produce low temperatures required by the detector system (SQUID chip and pick-up coil). A further miniaturization is also feasible, if one uses a current high-Tc superconductor technology. In this paper, we discuss the basic principle of the system and feasibility of space use.

Principles: The detection coil in a traditional MRI system is a typical Faraday induction coil. The induced voltage signal from a magnetized sample in a conventional MRI setup is proportional to the rate of change of the precessing magnetization, w_0M, by the Faraday's Law. The precessing (Larmor) frequency, w_0, of the magnetic signal from the sample (originated from nuclear spins of the sample) is determined by the static field, H_0 used in the measurements. Therefore, the voltage signal, w_0M is proportional to H_0^2, because the magnetization M is also proportional to H_0,. This makes it impossible to obtain a good image of samples at very low field, say less than a fraction of Tesla (T). However, in the low-field MRI system, the SQUID sensor combined with superconducting pick-up coil system will measure the magnetization M directly, independent of w_0. The signal from the sample, therefore, is linear in the polarization field H_0. This allows one to measure a small nuclear magnetic signal and image samples at low-field, ~0.05mT, by prepolarizing the sample in a modest (~0.1T) field and using a commercially available SQUID sensor. Another advantage of using ultra low field is associated with the field homogeneity requirements on a MRI magnet. In conventional MRI, the field produced by the magnet needs to be extremely homogeneous over the sample. To achieve a resonance signal linewidth (inversely proportional to the imaging resolution) of 1Hz, for instance, field homogeneity better than 0.15*m*T is required for a water sample. At 2.5 T field in conventional MRI systems, the required magnet field homogeneity is approximately a part in 10^8! This requirement is not trivial to achieve in a practical magnet design construction and will be progressively harder when one designs for space use. However, in the ultra low-field (~0.05mT, Earth field) MRI system, the same imaging resolution (1Hz linewidth) can be achieved using a magnet with 0.3% of field inhomogeneity. This is easily achievable. More importantly, imaging biological samples at low field has fundamental merits that can not be achieved in the conventional high-field MRI system. The frequency independent sensitivity in the SQUID-based low-field MRI system enables imaging capability of samples located even inside a metal housing. This is impossible in the conventional MRI due to the shielding effect. Also, a sample with metallic elements (for instance, the human body with in-vivo metallic implants) can be imaged without significant distortion. The T_1 contrast imaging, which utilizes the differences in the spin-lattice relaxation time constant (T_1) in different materials, is widely used in the conventional MRI to distinguish different types of biological tissues. In low field, the T_1 contrast imaging resolution is greatly improved. These unique merits associated with using the low-field for imaging will certainly advance the current medical diagnostic technology on Earth in the future. A low-weight, cryogen-free, low-field system can also be designed and built for future space applications. We will discuss recent development of a prototype system and design principles for space flight use.

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IN-SITU CALORIMETRIC MEASUREMENTS FOR SPACE EXPLORATION: AN INSTRUMENT CONCEPT. C. C. Hays, S. M. Hollen, M. Barmatz, and T. Chui, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, Charles.C.Hays@jpl.nasa.gov.

Introduction: Evidence for the presence of subsurface water ice at the moon's poles was supplied by radar images from the Clementine space probe and from neutron spectrometer data returned by the Lunar Prospector spacecraft [1][2]. However, the controlled crash of the Lunar Prospector probe into a crater at the Moon's south pole did not provide direct spectroscopic evidence from either Earth-based observatories or the Hubble Space telescope. It will be necessary for NASA to determine the existence, abundance, and properties of lunar water ice and the surrounding regolith. Any lunar mission that will conduct a quantitative study of the near-surface deposits or one that seeks to utilize these deposits for resource harvesting will require an in-situ method for determining the physical properties of the icy deposits, and the surrounding lunar regolith. These studies are particularly important to determine both the abundance of water ice as well as its form, which is likely to be amorphous [3]. Amorphous water ice is readily formed in extremely cold environments through vapor deposition, making it the most common form of ice in the universe [4]. The moon's permanently shaded polar craters, with temperatures near 40 K, provide a cryogenic environment favorable for the formation of amorphous water ice. Over astrophysical time scales, vapor deposition of water could be a physical process responsible for the existence of water ice at the moon's poles. These shaded craters would also preserve the remnants of ice delivered by ancient cometary impacts. We propose developing a mini-differential-scanning-calorimeter (mini-DSC) for in-situ measurements of regolith samples on lunar and planetary surfaces to determine the existence, abundance, form, and possibly the origin of lunar water ice.

Approach: Calorimetric instruments are the method of choice for determining the thermophysical properties of solids, liquids, and gases. The method is straightforward: an unknown specimen is placed in a small, insulated chamber, and on controlled heating, the temperature of the specimen chamber is compared to another nearly identical empty reference chamber. Phase and/or state changes in the unknown specimen caused by heating will be manifest in temperature differences between the unknown and reference chambers. These quantitative measurements would provide direct knowledge of the thermophysical properties of an icy deposit, such as specific heat, glass transition temperature, heat of crystallization, melting temperature, latent heat of melting, and latent heat of vaporization. If the specimen could be weighed, the abundance of ice in the regolith could also be determined. In addition to their value to space exploration and fundamental knowledge, these data are of critical importance for managing the heat loads of any water or oxygen extraction facility, which must include a method for controlling the imposed thermal loads, e.g., via a thermal radiator.

Prototype: For the purpose of studying amorphous ice here on earth before possibly encountering it on the moon, we propose to develop a prototype mini-DSC at JPL. In order to fully interpret the data to be taken with the mini-DSC, we will study the properties of amorphous water ice synthesized under conditions relevant to the Moon, including both vapor deposition and quenching tests. Further studies will examine: 1) the effects of water vapor deposition onto surfaces of lunar regolith simulant; and 2) the effects of dispersing small particles of the simulant into liquid water, and then quenching to form amorphous ice.

Method of Characterization: Our studies will also build on the reported properties of amorphous water ice prepared via vapor deposition. The phase diagram is complicated and dependent on the synthesis method; however, the widely adopted glass transition temperature is 136 K, and the crystallization of the amorphous phase occurs over the range 155-161 K. Additionally, the heat released upon crystallization of the amorphous ice is approximately 22.6 cal/g. This heat is nearly 1/3 the normal latent heat of melting for normal (hexagonal) water ice, approximately 79.9 cal/g. These properties, and our proposed research, will allow us to characterize lunar water ice. Furthermore, the magnitude of the heat of crystallization and its implications on managing heat loads mandate a full understanding of the cryogenic properties of amorphous water ice.

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NEOs AS MOON-MARS RISK AND COST REDUCTION. J. N. Head[1], C. R. Price[2], and B. R. Blair[3], [1]Raytheon, P.O. Box 11337, Bldg. 808/20, Tucson, AZ 85734-1337, [2]Raytheon, P.O. Box 12248, M/S 23, St. Petersburg, FL 33733-2248, [3]Colorado School of Mines, 1500 Illinois St., Golden CO 80401-1887

Introduction: Near-earth objects (NEOs) are easily accessible targets for proving technologies required for exploiting Phobos resources in a moon-Mars architecture. If successful, such a program would require but one more step to exploit NEOs for in-space propellants for lower cost than any other source. First order analysis shows that NEO propellant could be stored at L1 for $4-5 M/mT.

NEOs and Phobos Risk Reduction: Robotic precursors required for Phobos in-situ resource utilization (ISRU) include a reconnaissance orbiter, a raw sample return, and a processed sample return before Phobos propellants can be relied upon for human spaceflight. Each of these missions requires at least a four-year turnaround, driven mostly by the lack of samples, a situation quite different from lunar ISRU. Since Phobos is a D-type asteroid, and since D-type and related taxonomies are known in the NEO population, it is possible to practice techniques for Phobos ISRU on the NEOs. The great advantage is that while the round trip Δv is reduced, the travel time is less by a factor of ten, allowing an advance in the Phobos exploitation schedule. The precursors would be replaced with two New Frontiers-class survey and sample return missions (*cf.* Dawn), followed by a NEO ISRU demonstration. At this point an ISRU pilot plant could be sent to Phobos with much reduced risk. Alternatively, one could simply exploit NEO resources, since at this point the use of NEO propellants has been demonstrated for robotic missions. More than 10,000 NEOs 10 m or larger with round-trip $\Delta v < 4.2$ km/sec are thought to exist [1].

CONOPs: A depot at L1 includes a power plant, a plant for processing water into propellants, storage tanks, and a fleet of harvester spacecraft. On receiving notice that a terrestrial NEO detection system has spotted a NEO of the correct type, *e.g.*, D-class, in the right dynamical box, *e.g.*, total mission $\Delta v <$ ~5 km/sec, and of the right size, *e.g.*, larger than 15 m diameter, a harvester of 70 mT cargo capacity is dispatched with sufficient fuel to rendezvous with the NEO. Asteroidal material is collected and processed to water. A portion of this water is further processed to propellants for the return trip. The harvester returns *via* aerocapture to the L1 depot, off-loading water for purification and storage until it is needed to be processed to propellants. The outbound and inbound portions of the trip require ~30 days, with ~60 days of operations [1]. Target NEOs are assumed to be 5% bound water and processed with 50% efficiency. The dry mass estimate for the harvester is 11.4 mT and for the L1 depot is 25 mT. A fleet of five harvesters supports nine missions a year.

Market. The L1 propellant market includes 100 mT/yr for geotransfer operations [2], 50 mT/yr for lunar operations assuming an Apollo-like flight rate, and 250 mT/yr for Martian operations: 400 mT/yr total.

Operations Support. The required fuel to support operations is highly dependent on Δv and on harvester cargo capacity below ~50 mT. For 70 mT and Δv ~4.1 km/sec, *e.g.*, 1991VG, ~150 mT of fuel are required for operations. This means ~70% of the recovered NEO fuel is available for sale.

Cost Estimation: NAFCOM2002 estimates total cost of the L1 infrastructure at $5.7 B (FY04). The harvester fleet cost is $3.1 B, including $1.5 B for DDT&E and $1.6 B for the production of five units. Operational cost is assumed to be 10% of this total each year. Launch cost (no heavy lift) to place the depot and fleet on station is $1.6 B (FY04). The cost of NEO fuel at L1 is $4.8 M/mT assuming 30-yr amortization of development, production, and launch costs. If the L1 depot is already present as part of lunar ice mining operations, then the cost of NEO fuel at L1 drops to $3.7 M/mT. This compares favorably with the cost of lunar fuel at L1 ($5-7 M/mT) [2]. Cost of the precursor missions (including the terrestrial telescopic survey) is not included in the above estimates.

Preliminary business analysis shows that ROI of 170% can be expected with positive cash flow in the first year assuming fuel sales at $13.7 M/mT. If the L1 depot is already present as part of lunar ice mining operations, then the ROI is 240% for fuel sales at the same price. ROI estimates use a 15% discount rate.

Conclusion: It is clear that using NEOs to demonstrate technologies for Phobos ISRU can advance the schedule for crewed Mars exploration. It is also clear that using NEOs for Phobos risk reduction is one step short of exploiting NEO fuels. It appears that such fuels can be made available at L1 for much lower cost than terrestrial fuel and 10-20% less than lunar-derived fuels. NEO-derived fuel development offers time and cost savings to a moon-Mars architecture. A survey of NEOs to 10-m diameter is the first step in determining the viability of such an enterprise.

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PRODUCTION OF STEEL PRODUCTS IN SPACE USING ISRU IRON SOURCES AND CARBONYL METALLURGY. Bill Jenkin, Galactic Mining Industries, Inc., http://www.space-mining.com , 226 Elmdale Ave., Akron, OH 44313, 1-330-867-3628, milian@milianfrance.com

Abstract: Steel production of critical components using In Situ iron found in lunar, martian and asteroidal materials is done using carbonyl metallurgical techniques. Pressure vessel production will be focused on in this presentation. Carbonyl metallurgical processes involve the gaseous digestion of iron content using carbon monoxide. The resultant iron pentacarbonyl is used in Chemical Vapor Deposition processes to coat the interior or exterior of forms such as inflatables or other suitable mandrel surfaces. Such coatings build up to thicknesses necessary for use as pressure vessels, mirror contours, structural members and other important components for space bases and space stations.

Iron on the moon and mars will be reduced to the metallic state using hydrogen at elevated temps (700 to 900C), while iron found on asteroids is already in the metallic state and does not require preprocessing reduction. The iron must be in the metallic state in order for the carbonyl digestion process to take place. Digestion of metallic iron takes place at temperatures near 75 to 100 degrees Celsius. The Chemical Vapor Deposition (CVD) of steel takes place at temperatures near 175 to 200 degrees Celsius. These low temperature processes allow space manufacturing of critical components using In Situ Resources, thus multiplying the value of raw materials launched from earth. Raw materials are hydrogen gas for the reduction of iron, carbon monoxide for iron digestion, piping, pumps, heating apparatus, process control apparatus, inflatables (to provide shaped contours on which deposition takes place), materials to produce mandrel or mold surfaces, mining equipment capable of collecting soils and ores and grinding equipment. Magnetic separation may be used to concentrate iron content in raw ores and soils preparation. Gases such as hydrogen and carbon monoxide are recycled over and over again to permit large quantities of steel products to be produced with a limited initial supply of process gases and equipment.

Long term space programs will be able to accomplish much more by the use of In Situ Resources as feedstocks in the manufacture of critical components and equipment. Compared to the manufacture of steel on earth in high temperature foundries, these carbonyl processing techniques are low temperature techniques. Limited quantities of equipment and process gases are able to process many times their weight in iron to produce many times their initial weight in steel products.

William C. Jenkin, age 92, with 17 U.S. Patents, and has spent 45 years as a pioneer pursuing technology and applications of the CARBONYL CVD (chemical vapor deposition) PROCESS, proposed as a means to establish a metal fabrication technology on the moon.

A pioneer who was never downsized or unemployed, Bill began as a chemistry major at Oberlin College (class of ’35), and became Chief Chemist in charge of a manufacturing quality control lab of 12 technicians and chemists at Thompson Products, of Cleveland, Ohio. In 1946, Bill formed and sold Midwest Precision Casting to develop and successfully employ the precision investment process.

In 1958, he joined Commonwealth Engineering, an Ohio contract R&D firm, as Project Manager of research primarily in nickel CVD. In 1968, Bill formed and managed the PYROLYTIC DIVISION of Akron Standard Mold, to develop nickel CVD into an industrial technology for use in low pressure molding of plastics. By 1972, production technology was developed in nickel shells weighing up to 100 lbs and as long as 6 feet were made. From 1972 to 1992, there was continuous production of nickel shells, mostly molds, up to 200 pounds by successor organizations. Bill finally set up and operated his own laboratory to continue contract research in nickel CVD until 1989, when he contracted exclusively for INCO in a search for industrial applications.

The technology Bill Jenkin pioneered and developed led to formation of two manufacturing operations in Wales, UK, and a contract with partners in Utah using his patented nanostrand technology. Bill is currently a partner with Galactic Mining Industries, Inc., to develop carbonyl manufacturing for mining and steel production on the moon, asteroids and on mars.

Galactic Mining Industries, Inc. is a Colorado C-Corporation based in Denver, Colorado. The president of Galactic Mining Industries, Inc. is Richard Westfall, mail@space-mining.com . Galactic Mining Industries, Inc. was originally founded in 1989 and has been pursuing the commercialization of space technologies useful in the colonization of space.

A Computer Model to Predict Excavation Forces for Design of a Lunar-Regolith Bucket-wheel Excavator L. Johnson,[1] R. H. King,[2] M. B. Duke[3], and [1]Engineering Division, Colorado School of Mines, 1500 Illinois, Golden, CO 80401 (ljohnson@mines.edu), [2] Engineering Division, 279 Brown Hall, Colorado School of Mines, 1500 Illinois, Golden, CO 80401 (rking@mines.edu), [3]\ Institute for Space Resources, 234D GRL, Colorado School of Mines, 1500 Illinois, Golden, CO 80401 (mduke@mines.edu).

Introduction: President Bush announced the intent to return to the Moon and to further explore Mars and beyond in January 2004, increasing the interest in In-Situ Resource Utilization (ISRU) to produce hydrogen, oxygen, and water from lunar regolith with small unmanned plants. A robotic excavator is essential to provide regolith material to the plant. The excavator must generate sufficient force to dig cohesive lunar regolith in lunar gravity, but design factors common to terrestrial excavators are not practical because of mass (< 80kg) and power (< 50 W) limitations. This requires a new approach to design a micro-excavator with a small design factor.

Background: There are several models for simulating the forces from soil-tool interaction. For example Luth and Wismer (1971) and Wismer and Luth (1972) empirically developed models used to analyze Mars Viking-mission scoop forces. They developed relationships that estimate reaction forces on a blade in cohesionless sand and for cohesive materials:

$$F_x = \rho g b z^{0.5} l^{1.5} \alpha^{1.15} \left\{\frac{z}{l\sin(\alpha s}\right\}^{1.21} \left\{\left(\frac{11.5C}{\rho g z}\right)^{1.21} \left(\frac{2V}{3b}\right)^{0.121} \left(0.055\left(\frac{z}{b}\right)^{0.78} + 0.065\right) + 0.64\frac{V^2}{gl}\right\}$$

$$F_z = \rho g b z^{0.5} l^{1.5} \left(0.48 - (\alpha - 0.70)^3\right) \left\{\frac{z}{l\sin(\alpha)}\right\}^{0.777} \left\{\left(\frac{11.5C}{\rho g z}\right)^{0.41} \left(\frac{2V}{3b}\right)^{0.041} 9.2\left(1.31\left(\frac{z}{b}\right)^{0.225} 5.0\right) + 0.24\frac{V^2}{gl}\right\}$$

Where ρ = soil density, g = acceleration of gravity, b = blade width, l = blade height, α = blade inclination angle, z = operating depth, V = velocity, and C = cohesion.

BWE Excavation Reaction Force Model: The Luth and Wismer model is for a simple flat blade moving horizontall through soil with agricultural plowing applications; nevertheless it was developed for a small blade, on the scale of our application whereas other excavation models are for much larger scales. Consequently, we modified it for a micro-excavation application. Muff et al (2004) concluded a bucket-wheel concept was appropriate for extraterrestrial applications and modified it to micro scale as shown in **Error! Reference source not found.**.

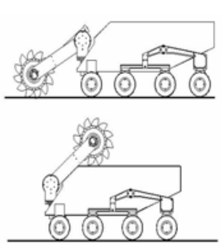

Figure 1. Lunar Bucket Wheel Excavator Concept Sketch

We then modified the plowing model with the circular motion of the bucket wheel and the forward motion of the rover by continuously changing depth of cut, cut angle, and forward velocity:

$$\vec{V}_{b-average'}(t) = \left(V_f + \frac{H_b}{2}\cdot(H_b - 2R_c)\cdot\omega_c\cdot Cos[\omega_c\cdot t + n\cdot\theta_b]\right)\hat{i} + \left(\frac{H_b}{2}\cdot(H_b - 2R_c)\cdot\omega_c\cdot Sin[\omega_c\cdot t + n\cdot\theta_b]\right)\hat{j} + 0\hat{k}$$

Where Vb = velocity at the middle of the bucket and averaged across its surface, t = time, H_b = the height of the bucket (5 cm), R_c = the radius to the bucket tip, ω_C = bucket wheel rotation angular velocity, n = number of buckets, and θ_b = the angular spacing between buckets. Unit vectors of i, j & k denote direction. The velocity of the bucket is the x component.

$$Z1 = \left|-\sqrt{R_c^{\,2} - x^2} - \sqrt{R_c^{\,2} - (x + FDOC)^2}\right|$$

$$\text{Where: } FDOC = \frac{V_f \cdot Cos^{-1}\left[\dfrac{R_c - DOC}{R_c}\right]}{\omega_c}$$

$$Z2 = \left|-\sqrt{R_c^2 - x^2} - (-R_c + DOC)\right|$$

Where: Z1 and Z2 = operating depth in two regions of extraction, x = x component of the bucket tip position, DOC = depth of cut, and FDOC = forward DOC. The inclination angle (α) of the bucket/blade is calculated by subtracting the current bucket angle from $^{\pi}/_{2}$.

Results: We implemented the model interatively in LabVIEW with example results shown in **Figure 2**.

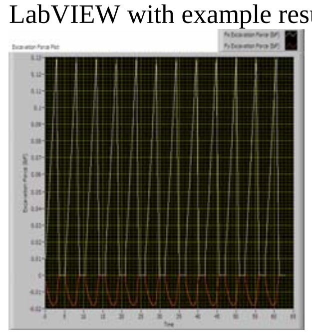

Figure 2. Example Excavation Force Plot

References: Luth, H. J. and R. D. Wismer. "Performance of Plane Soil Cutting Blades in Sand." ASAE Trans, 1971, Vol. 14, pp 255 – 262.

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Wismer, R. D. and H. J. Luth. "Performance of Plane Cutting Blades in Clay." ASAE Trans, 1972, v. 15, pp 211 – 223.

CO_2 LASER-HEATING EXPERIMENTS ON APOLLO 11 LUNAR FINES 10084. J. L. Jordan[1] , G.M. Irwin[2], and S. A. Miller[3], [1]Department of Earth and Space Sciences, P.O. Box 10031, Lamar University, Beaumont,Texas 77710, jordanjl@hal.lamar.edu, [2]Department of Chemistry and Physics, P.O. Box 100xx, Lamar University, Beaumont, Texas 77710, irwingm@hal.lamar.edu , [3]Department of Earth and Space Sciences, P.O. Box 10031, Lamar University, Beaumont, Texas 77710.

Introduction: We report Mössbauer spectroscopy and mass spectrometry measurements on CO_2 laser-heated Apollo 11 lunar fines 10084. The purpose of these experiments of these experiments was to determine the power density for releasing solar wind implanted gases from lunar fines and the power density required for complete melting of the fines. Such information provides constraints on the use of the CO_2 laser and other heating techniques in resource exploration and resource processing of the lunar regolith[1,2}.

Laser-heating experiments: For the Mössbauer spectroscopy measurements heating experiments involved three 10 minute rasters, with sample homogenization between rasters, with laser power settings at 2, 3.5, 5, 7, and 10 Watts, in a vacuum of $\sim 10^{-3}$ torr. For the mass spectrometry measurements the sample was exposed to the laser for one minute in a vacuum of 10^{-9} torr before measurement of the released gases.

Mössbauer spectroscopy measurements. The purpose of the Mössbauer measurements was to characterize the glssification of the material from partial to complete melting, and in particular to note the changes in the ilmenite component, which is a primary retainer of solar wind gases. A four component method was used to fit spectral lines. This method allowed extraction of relative absorption due to ilmenite (crystalline Fe^{3+}) and glassy Fe^{3+}, as well as Fe^{2+} silicate phases. Fig. 1 shows the results for the heated lunar sample 10084. Note that the increase of total Fe^{3+} content (filled circles ●) is equal to the decrease in Fe^{2+} (open circles ○), indicating that some of the ferrous silicates are oxidized in the heating process.

Mass spectrometry measurements. We measured the release of He, Ne, and Ar from lunar sample 10084 as a function of laser power with the SXP 50 quadrupole mass spectrometer in our laboratory. These inert gases were chosen to represent the mass range of most volatile gases of interest, and to avoid complexities that may result from reactive gases

The released gases were subsequently measured. Solar wind origin of these gases was confirmed from the $^4H/^3He$,$^{20}Ne/^{22}Ne$, and $^{40}Ar/^{36}Ar$ ratios. The quantities given in ccSTP were obtained from the measured signal and an instrument calibration from known quantities of the gases of interest. The results shown in Fig.2 indicate that peak release occurs at approximately 2W and degassing is nearly complete above 3W.

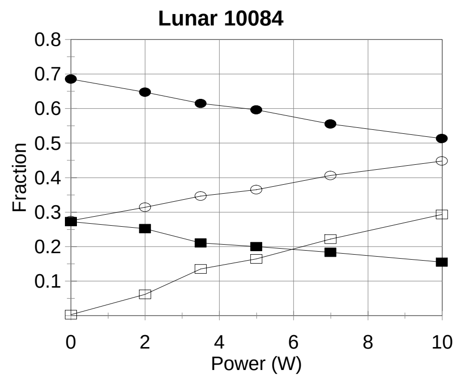

Fig. 1 Phase analysis of the heated lunar sample 10084. (●) Ferrous silicate (Fe^{2+}), (○) Total Ferric (Fe^{3+}), (▪) Crystalline Fe^{3+} (Ilmenite), (▫) Amorphous Fe^{3+}.

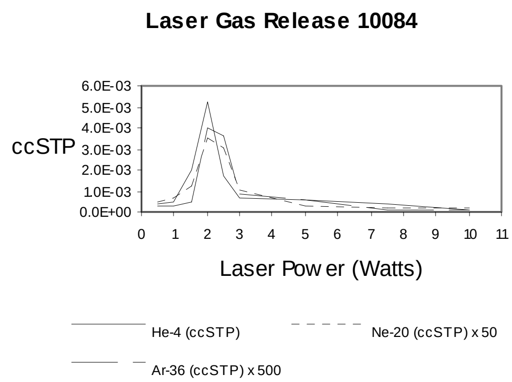

Fig. 2 Laser release pattern for He, Ne, Ar from 10084

Conclusion: The laser power density (W/cm^2) for complete melting determined from Mössbauer spectroscopy measurements of the heated material is in the range 80-100 W/cm^2 . The mass pectrometry measurements results correspond to a power density range between 25-35W/cm^2 for near complete release of solar wind implanted gases.

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EVALUATION OF LUNAR-REGOLIGH EXCAVATOR CONCEPTS FOR A SMALL, ISRU OXYGEN PLANT.

R. H. King,[1] M. B. Duke[2], and L. Johnson[3] [1]Engineering Division, 279 Brown Hall, Colorado School of Mines, 1500 Illinois, Golden, CO 80401 rking@mines.edu), [2] NASA Institute for Resource 234D RL, Colorado School of Mines, 1500 Illinois, Golden, CO 80401 mduke@mines.edu.

Introduction: The Precursor In-situ Lunar Oxygen Testbed (PILOT) program is developing a system to produce 2 kg of liquid oxygen per day from the lunar regolith. During Phase 1, candidate technologies for three subsystems, resource collection, oxygen extraction, and oxygen storage, are being analyzed and evaluated to develop a preliminary design that will meet the following goals:

- 60 kg LOX per month, minimum
- 120 kg LOX per month target
- 400 kg system mass – Includes Excavators; includes power production; LOX storage
- Power <3 kWatt
- Operational life > 2 years
- Storage capacity - 300kg

With the following mass budget:

- Power Generation – 50kg
- Regolith Excavator – 80kg
- Oxygen Production – 140kg
- LOX Storage – 100kg
- Margin – 20kg

This paper reports on an evaluation of candidate concepts for the resource collection subsystem. The results are displayed in a decision matrix in Table 1.

Table 1. Lunar Excavator Concept Decision Matrix

Criteria: Primary	Criteria: Secondary	Secondary Weight	Primary Weight	Bucket Wheel	Auger	Backhoe w/ Forklift	Backhoe & Truck	Boom Excavator w/ Forklift	Boom Excavator & Truck	Bucket Chain	Front-end Loader w/ Forklift	Front-end Loader & Truck	Front-end Loader & Rake	Overshot Loader	Scraper	Shovel w/ Forklift	Shovel & Truck
Capable			17	16	13	16	14	16	14	15	16	13	15	13	7.5	16	14
	horizontal reaction force	40		39	36	40	37	40	37	38	40	37	38	37	20	40	37
	vertical reaction force	45		42	33	45	31	45	31	38	44	29	38	29	20	45	31
	ease of internal material handling	5		3	5	5	5	5	5	4	5	5	5	5	2	5	5
	maximum particle size	5		5	0	5	5	5	5	5	5	5	5	5	0	5	5
	sizing capability	5		5	2	2	2	2	2	2	2	2	2	2	2	2	2
Integrateable	ease of material transfer		14	14	14	10	7	10	7	14	10	7	7	14	14	10	7
Reliable			14	12	11	13	11	12	11	13	13	11	9	13	11	13	11
	number of major subsystems	30		15	23	23	23	23	23	23	23	23	15	23	30	23	23
	number of motors	30		28	29	27	16	27	15	29	29	18	17	29	30	27	16
	proven technology	20		20	10	15	20	10	15	10	15	20	10	15	10	15	20
	material transfer points	15		12	0	15	15	15	15	15	15	15	15	15	0	15	15
	dust generation	15		12	15	15	8	15	8	15	12	6	6	12	12	15	8
Stable	tipping forces when loaded		14	14	14	6	8	6	8	14	10	12	12	14	14	6	8
Controllable	telerobotic		10	10	10	8	4	8	4	10	6	2	2	8	8	8	2
Productive	cycle time		8	8	8	4	4	4	4	8	4	4	4	6	6	4	4
Cost effective			7	6	6	6	4	6	4	6	6	4	4	7	7	6	4
Multi-functional			7	5	4	6	7	6	7	5	6	7	7	6	4	6	7
	dispose of reactor waste	50		40	40	40	50	40	50	40	40	50	50	40	40	40	50
	support habitat construction	25		10	5	20	25	20	25	10	20	25	25	20	5	20	25
	explore	25		15	5	20	25	20	25	15	20	25	25	20	5	20	25
Power efficient			7	6	7	6	4	6	4	7	7	4	4	7	7	6	4
Maintainable	suited or robotic		2	2	2	2	1	2	1	2	2	1	2	2	2	2	1
Total			100	93	88	77	64	77	63	93	79	66	66	89	81	77	62

Method: The decision matrix was developed with an eight-step hierarchical multiple criteria decision analysis process:

1. Specify the product design
2. Develop a hierarchy of criteria from the specification.
3. Generate alternative concepts.
4. Get information about each concept that can be used to quantitatively score it for each criterion.
5. Give each criterion a weight using the pair-wise comparison method.
6. Evaluate with a decision matrix. Compare the sum of scores of each alternative.
7. Revise the concepts (eliminating, combining, modifying)
8. Re evaluate iteratively until the group of evaluators is satisfied

There is considerable experience on earth with surface mining that was applied to the problem. However the special constraints of lunar operation (low gravity, high cost to deploy, no infrastructure, no human presence, extreme thermal environment, dust adhesion, and solar radiation) required rethinking earth mining equipment. Therefore the concepts used a baseline extraterrestrial bucket-wheel excavator (BWE)in Figure 1 a dramatic modification to the terrestrial BWE.

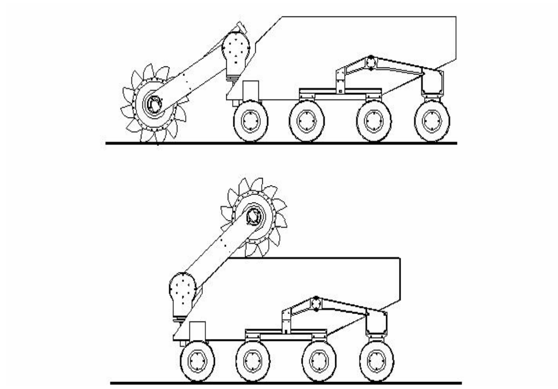

Figure 1. Lunar Bucket Wheel Excavator Concept Sketch

We analyzed the purpose, enabling characteristics, functional requirements, functional constraints, performance metrics to develop the list of criteria shown in Table 1 assuming a set of common capabilities for all concepts:

- Mobility Platform – Similar to the Sojourner.
- Power – On-board batteries recharged by solar.
- Reaction Forces – 0.4 * Load/wheel in lunar gravity.
- Material Transfer – dump bed
- Waste Dumping – dump bed on return trip.

We developed a specification table for each concept that provided input data to models that calculated evaluation scores shown in Table 1. The scores where multiplied by the criteria weights and summed.

Results: The three-highest scoring concepts, BWE, Bucket Chain, and Overshot Loader will move to the next stage of the process, computer simulation and modeling.

LUNAR SURFACE EXPLORER: A ROVER-BASED SURVEYOR SUITABLE FOR MULTIPLE MISSION SCENARIOS. David A. Kring[1], Joel Rademacher[2], Ben Dobson[3], John Dyster[2], John Kopplin[2], Dave Harvey[3], and Chris Clark[2], [1]Lunar and Planetary Laboratory, University of Arizona, 1629 E. University Blvd., Tucson, AZ 85721 (kring@LPL.arizona.edu), [2]General Dynamics C4 Systems, 1440 N. Fiesta Blvd., Gilbert, AZ 85233, [3]Aerospace & Deployable Structures Division, Foster-Miller, Inc., 350 Second Ave., Waltham, MA 02451.

Introduction: An important component of NASA's Vision for Space Exploration involves a series of robotic missions on the lunar surface, beginning with analyses of permanently shaded regions at the lunar poles to determine if water is stored in the regolith. We propose a lander and rover concept that will generate direct *in-situ* analyses of any volatile components in multiple samples of the regolith. The rover-based mission architecture is robust and affordable and can be used repeatedly for other scientific and testbed lunar missions.

Mission Architecture: Sampling the regolith in permanently shaded craters places operational constraints on the sampling unit. It must rely on either batteries or energy provided from a remote lander in sunlight. Also, the sampling unit must be able to operate in the cold of the shaded region that can approach 40 K. A means of communication with Earth from the shaded region, which may or may not have a line of sight to Earth, must also be provided.

We propose a small rover, deployed from, and in communication with, a lunar lander, which can then relay data to a lunar orbiter and on to Earth (Fig. 1). The lander can provide tethered power and local communications to the rover which is released into shaded lunar craters. The rover can be untethered for missions where solar arrays can be illuminated. Power required by the rover is minimized by offloading data storage and most communication tasks to sunlit elements on the lander, allowing the rover subsystems to be sized to perform only their payload sampling and analysis tasks.

The rover with science payload weighs a total of 50 kg including 30% margin. The electrical power system consists of a single solar array, a charge control unit, and a rechargeable battery. The rover communicates with the lander over a wireless link; the lander stores and relays the data. This lander-rover approach offers the ability to select and negotiate a path to sampling sites in a rugged terrain. The rover battery can be recharged for longer mission requirements via a lander tether or an onboard solar array.

Rover: Utilizing its extensive experience with terrestrial rover design, Foster-Miller, Inc. (FMI), has developed a concept for a general purpose lunar rover. FMI currently produces a line of small rover vehicles for various military and civilian applications. Of these, the Talon robot vehicle is the most widely used, with hundreds of units deployed around the world with the U.S. military, performing reconnaissance and ordnance disposal missions. This experience suggests two design principles need to be emphasized on the Moon. First, the rover must be operationally robust to provide a platform for diverse instruments and operate in a severe environment. Second, the rover must be reliably mobile, with the rover design driven largely by mobility system requirements, which ensures that the rover will remain mobile even if navigational or human errors occur in difficult terrain.

The rover consists of two tractive modules, each of which is a sealed unit enclosed by an elastic loop, or track. The tracks will provide superior traction, operational efficiency, and operational simplicity, especially in uneven terrain, as compared with a wheeled rover. Any additional mass and small losses of turning precision due to tracked vehicle design are offset by the increased reliability of the resulting mobility system. The tractive modules are slightly separated and connected by a single large spar that provides a bridge for power and data. The spar also includes a joint that allows relative pitch between the modules. The spar serves as a mounting location for a multi-stage arm that stows between the tractive modules. This arm can be fitted with various sampling tools and analytical instruments, and it provides much of the required operational flexibility. Additional static instruments can be mounted to the outsides of the tractive modules.

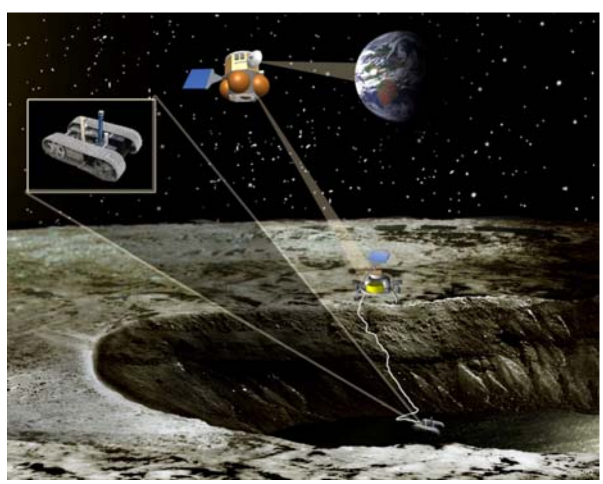

Fig. 1. Lander-Rover concept with wireless and/or tethered communication and power systems.

EXPLORING IMPACT CRATERING ON THE MOON AND ITS IMPLICATIONS FOR THE BIOLOGIC EVOLUTION OF, AND HABITABLE CONDITIONS ON, THE EARTH. David A. Kring[1], Timothy D. Swindle[1], Robert G. Strom[1], Takashi Ito[2], and Fumi Yoshida[2], [1]Lunar and Planetary Laboratory, University of Arizona, 1629 E. University Blvd., Tucson, AZ 85721 (kring@LPL.arizona.edu), [2]National Astronomical Observatory, Osawa, Mitaka, Tokyo 181-8588 Japan.

Introduction: The Apollo era revealed that the Earth and Moon have been the target of impacting asteroids and comets far more frequently than that suggested by the small number of surviving impact craters on Earth. Because the missions returned samples to Earth, an absolute chronology of the impact flux began to grow. When combined with a relative impact chronology provided by extensive ejecta blankets (strata) and crater densities on different lunar terrains, the data indicate most impact craters on the Moon were produced during an early period of bombardment and that the last of the great basin-forming impacts occurred ~3.85 Ga. We now understand that similar impact cratering events on the Earth had the potential to affect the origin and evolution of life on our planet. Because impact cratering is continuing process, we also realize that the processes, even at scales far smaller than basin-forming events, pose a hazard for modern life. However, the details of the impact flux remain murky, because so few samples have been analyzed and many of those analyzed are without geologic context. Consequently, one of the most important scientific goals of renewed lunar exploration, both robotic and human, will be to collect appropriate samples to deduce impact cratering's effect on the fabric of life on Earth.

Early Earth Bombardment: Ar-Ar, U-Pb, and Rb-Sr analyses of Apollo-era samples suggest early bombardment may have been particularly intense in a ≤200 Ma interval that ended ~3.85 Ga [1-3], which is consistent with more recent analyses of lunar meteorites [4,5]. Although the source of debris remains controversial, chemical fingerprints in lunar impact melts suggest an asteroid source [6], which was recently confirmed with an analysis of the size distribution of projectiles needed to produce ancient lunar craters [7]. This is also a process that appears to have affected the entire inner solar system [6,8] and, thus, potentially habitable conditions on early Mars too [6,9].

The volume of data is still insufficient, however, and the hypothesis of a brief period of bombardment needs to be tested with additional sample analyses. Specifically, a collection of impact melts unambiguously tied to large craters and basins are needed for detailed petrologic, geochemical, and radiometric age analyses. These should be selected to represent the entire distribution of relative ages among large basin-forming events, and of lunar geophraphic locations.

These same samples can also be used to test the source of projectiles. This will, in turn, permit an analysis of the delivery of biogenic elements during, and environmental consequences of, the bombardment. Some of the consequences were detrimental, but these same impact events may have generated vast hydrothermal systems that were critical for the origin and early evolution of life [9-11]. If the bombardment did not begin until ~4.1 Ga or later, then these results will also have dramatic implications for the accretion and orbital evolution of outer system planets [7,12]. Furthermore, the collisional evolution of the early solar system may help guide our interpretation of the geologic evolution and potential biologic viability of other planetary systems [e.g., 13].

Post-Bombardment Impact Flux: The Chicxulub impact crater and its link to the K/T (K/P) mass extinction event demonstrates that the post-bombardment impact flux was still sufficient to cause dramatic biological upheaval. In addition to the flux of sporadic impact events, it will be important to determine if there were particularly intense storms of impact activity, hints of which occur in the Archean, at 800 Ma, and 500 Ma. This requires precise analyses of impact melts ages from a moderate number of post-3.8 Ga impact craters and an accurate determination of the relative number of impact events that occur between those absolute benchmark ages. These analyses will allow us to determine the role impact cratering has had in the biologic evolution of Earth (both in terms of mass extinctions and evolutionary radiations), how impact cratering has perturbed the climate, and the hazards other impactors pose for Earth today and in the future.

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ORGANIZATIONAL CONCEPT OF BUILDINGS OF LEVELLED TEMPERATURE INTERIOR SPACE ON THE MOON.
J. Kummert[1], B. Boldoghy[1], Sz. Bérczi[2], I. Szilágyi[3], T. Varga[3], [1] Ferroelektric Engineering Pan Konceptum Ltd., H-1116 Budapest, Vasvirág sor 72., Hungary, (konceptum@vipmail.hu), [2]Eötvös University, H-1117 Budapest, Pázmány P. s. 1/a., Hungary (bercziszani@ludens.elte.hu), [23]VTPatent Agency, H-1111 Budapest, Bertalan L. u. 20., Hungary (info@vtpatent.hu),

Summary: We propose a building conception: the inner temperature of the lunar base buildings is primarily ensured by incoming solar radiation (plus a supplementary energy source) which also uses the inner lunar thermal energy.

Discussion: Any long-term stay and activity of human beings require providing appropriate temperature for them, in a range as close to that of the conditions on the Earth as reasonably possible. From needs of cost-effective use of energy [1] it follows that the required temperature should be ensured from the energy gained locally. The inner thermal energy of the Moon is minor so utilization of the radiating energy of the Sun plays the main role in supplying the suitable energy for heating lunar buildings [2].

The problem: Because of the lack of atmosphere for facilities exposed to the lunar surface the solar insolation on solar side and thermal emission on the other side means extreme thermal load. (daylight warming up can reach 400 K (+130C) temperature, at lunar night the lowest temperature is 100 K (–170 C).) This rate of temperature fluctuation is 300 K on the surface , however , because of the low thermal conductivity of the regolith, lower fluctuation amplitude can be found in deeper layers. This subsurface thermal environment seems more promising when locating a lunar base building is considered. This temperated value at subsurface is abt. 250 K (-20 C). In planning the lunar architectural environment, for the buildings this temperature average was considered.

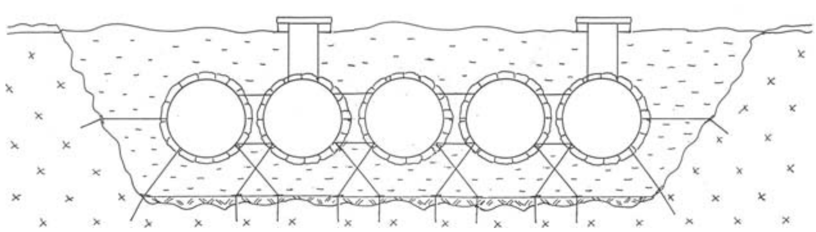
Special architectural requirements: In order to provide a steady, levelled temperature of the building: 1) we transport and utilize the maximum of the solar irradiation, 2) we minimize, diminish the thermal emission of the building to the lowest possible level by insulation. The essence of the solution according to our proposal: 1) During lunar daylight the energy of the outer sunshine is taken into the building and it is partially stored there, 2) During the lunar night a) the stored energy is utilized to provide the inner temperature of the building, b) the average thermal energy of the Moon is utilized, 3) For the location of the building the geological structures on the Moon (ditches, valleys, craters) are utilized. 4) For thermal insulation purposes the lunar regolith is used.

Educated guess: In the depth of 10-15 m the stable average temperature is 250 K (-20 C) (this value is valid near the equatorial region of the Moon). The essence of our proposal is that 1) the building of the lunar base should be placed into subsurface environment, and 2) regolith should be used as insulator. For the construction of this subsurface environment a ditch or valley is suitable. It can ensure the solid ground for placing the building, after reinforcement of the ground. Next, in a given section the valley can be filled up so that the suitable thermal-physical environment can be established for the buildings. The total height of cover is 15 - 25 m. This location results in the additional advantages 1) the building can be approached in the valley from side direction, 2) it is not necessary to provide vertical transportation. (In vertical direction only the pit collecting heat, or conduits for light intake should be formed.) 3) When the construction of the building is continued, it should be extended in the direction of the ditch or valley.

Feasibility Study: Local materials, that can be used: 1) as thermal insulator: regolith, fractioned as required by users, 2) as heat-storing material: some selected components extracted from the lunar regolith or the basalt. **Materials to be delivered** there: 1) fittings, materials for the frame structure, binding materials, 2) devices, machines, equipment for engineering (robot, resp. human participation), 3) assembled units: building structure (assembled on the Earth) with partial in-site assembly and local completion. **Human resources**: minimum six, preferably eight people. **Machines:** transport vehicles, hoister, excavator, hand tools, 1) it is worth developing a drag-line ensuring moving and manipulation of regolith, 2) operation of mechanical devices is possible partially by robot or by remote control way. **Regolith delivery and final emplacement time:** depending on preliminary preparations minimum half a lunar day, (14 days on the Earth) during daylight on the construction locality.

In order to reduce costs, the bulk of units to be delivered from the Earth must be diminished, as sinking into the regolith will provide them with every necessary mechanical and radiation protection. If buildings are properly located only minimum surface treatments of walls are needed.

References: [1] Boldoghy et al (2005): Functional program of buildings for conditions on the moon. This volume, [2] Kummert et al (2005): Using the sun's radiating energy for heat-storage as energy source of buildings on the Moon. This volume. [3] Boldoghy et al (2005): Planning project for establishing buildings on the moon to be operated cost-effectively. This volume.



USING THE SUN'S RADIATING ENERGY FOR HEAT-STORAGE AS ENERGY SOURCE OF BUILDINGS ON THE MOON. ***J. Kummert*[1], *B. Boldoghy*[1], *Sz. Bérczi*[2], *I. Szilágyi*[3], *T. Varga*[3],** [1] Ferroelektric Engineering Pan Konceptum Ltd., H-1116 Budapest, Vasvirág sor 72., Hungary, (konceptum@vipmail.hu), [2]Eötvös University, H-1117 Budapest, Pázmány P. s. 1/a., Hungary (bercziszani@ludens.elte.hu), [23]VTPatent Agency, H-1111 Budapest, Bertalan L. u. 20., Hungary (info@vtpatent.hu),

Summary: We think, that the thermal energy radiating from the Sun should be forwarded and concentrated by mirrors into a unit, where the received heat is stored by changing of the aggregate or phase of solid material. Retrieving of the heat takes place as required by fractionally reversing the changes.

Introduction: The aim of the proposal is to work out solution for the optimal receipt, storing as well as efficient utilization of the radiation arriving in the Moon in the sunny period as energy resource for the buildings.

Discussion: There are two ways of providing the required temperature for lunar base 1) an energy-source supplied from the Earth, 2) the utilization of the energy gained locally.

Local possibilities*:* Though the Moon has inner thermal energy, but the quantity of energy to be gained from it directly is minor compared to the demands. The other local energy source is the radiating energy received on the Moon from Sun. This energy, during the 14 earth-day long sunny period the surface could play an important role in the supply of suitable temperature for the lunar base buildings. The rate of this radiation on the Moon is the same as on the Earth, (but without absorbtion and scattering effect of atmosphere).

The essence of our proposal*:* The heat received by radiation is stored by heat-storing crystals, from which the heat can be gradually regained in the shadowy period. This technology involves 3 tasks: 1) Receipt and intake of solar energy of two-week intermittent periods, 2) Storing, 3) Continuous and regulated output meanwhile and during shadowy period. **Heat intake:** Continuously with a mirror system automatically following the Sun (energy concentration) focusing rays into a channel which reflects them into a heat-storing material, in given case to salt (changing its aggregate or phase, or melting it.) **Heat-storing:** Placing the heated, (or melted) heat-storing material in an insulated material. **Heat retrieving:** The heat-storing material egresses the heat during a heat-exchanging process, while it sets, e.g. changes into solid salt.

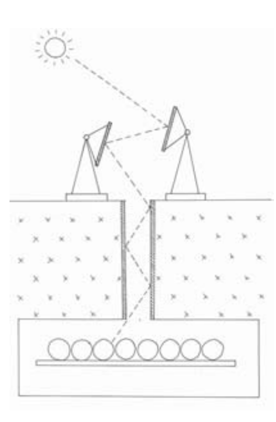
Theoretical concepts*:* The possible methods of heat-storing: 1) heating of heat-storing material, 2) change of aggregate, 3) change of crystal-structure.

1) By heating the heat-storing material: The quantity of the heat depends on the specific heat, the mass as well as the change of temperature of the heat-storing material. $Q=c\ m\ \Delta t$. This storing method is less effective.

2 and 3) By utilization of the change of phase or aggregate: In this case the material can take in a big quantity of heat with minor change of temperature. The quantity of heat depends only on the heat and bulk of the change of phase (melting, freezing) of the heat-storing material. $Q = c_o\ m$. This is a more efficient method.

Heat-storing by the change of a material phase or an aggregate in lunar conditions has adventages on the Moon compared to the case on Earth): 1) it can be a change of aggregate of higher temperature, 2) radiating period is considerably longer (14 days) 3) metals, salts, material-compozites, whose chemical composition does not change due to this melting, can be considered as heat-storing materials (low melting point materials are suitable for this procedure in a comparatively low temperature range).

Experimental type description: It would be important, that material used for storing heat: e.g. some variant of a salt, could be produced from lunar rocks, (in terrestrial conditions salts of sulfur content are applied). Local regolith of basalt content, moon dust, so that it could be produced locally, no delivery should be necessary.



Transferring heat into the heat-storing material: Applying one of the solutions of heat intake, the heat-storing material must be moved on the site of intake in the same rate as the rate of energy intake. (It has benefits if only a mirror moves radiating the heat onto given block, or surface).

Practical solutions: 1) heat-storing material is moved in a mechanical conveyor to the place of heating, respectively removed from there the same way, 2) a bigger block of heat-storing material is formed, which is rotated in a carousel below the place of radiation, 3) the heat-storing material melts, it can be flown from the place of heating. (It has benefits if only a mirror moves radiating the heat onto given block, or surface) The first collecting mirrors can be foil-mirrors fixed to a simple frame structure. The additional projecting and focusing mirrors are mechanically stable metal or glass mirrors of small loss, which project the compiled great energy-stream to the heat-storing material. It is important that the heat-utilizing unit must be part of the human habitable residence, preferably in the centre of it.

Materials to be delivered to the Moon: 1) mirrors and manipulating structures, 2) units for holding and moving the heat-storing material, 3) heat-exchangers, 4) structural frame of heat-utilizing unit, 5) either with assembly on the Earth or transporting it as a whole unit, or partial local assembly and local completion, 6) heat-storing material in special case.

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SUPERBOTS ON THE LUNAR SURFACE: A HABITAT OPERATIONS AND MAINTENANCE SYSTEM (HOMS).
S. J. Lawrence[1], G. J. Taylor[1], R. C. F. Lentz[1], L. M. Martel[1], W.-M. Shen[2], P. M. Will[2], M. H. Sims[3], S. Colombano[3], D. Kortenkamp[4], B. Damer[5], W. Chun[6]; [1]HIGP, University of Hawaii at Manoa, Honolulu, HI 96822; slawrenc@hawaii.edu; [2]ISI, University of Southern California, LA, CA; [3]NASA Ames Research Center, Mountain View, CA; [4]Metrica, Houston, TX; [5]DigitalSpace, Santa Cruz, CA; [6]Lockheed Martin, Denver, CO.

Introduction: SuperBots represent a departure from the paradigm of single purpose robots for single missions to a more mature and evolved philosophy that emphasizes multifunctionality, modularity, and reconfigurability [1]. The SuperBot system consists of a set of interlocking autonomous robotic modules that can *self*-reconfigure into different systems for different tasks. This design philosophy reduces cost and payload mass while enhancing mission performance, reliability, and safety through the SuperBot system's ability to change shape and function as needed. SuperBots can work independently or in concert to perform a wide range of tasks [e.g. 2 and 3].

For the foreseeable future, astronaut extravehicular activity (EVA) time will be at a premium on the lunar surface. It is neither practical nor desirable to expect astronauts to perform all extravehicular functions during the course of a lunar mission. However, many of the expected tasks at a lunar facility will require extensive EVA time. Therefore, a need exists for a robust robotic system that can accomplish an assortment of EVA tasks while controlled by either the crew or from the ground [4].

The HOMS Concept: Our vision of a SuperBot teleoperated habitat inspection and repair system is called the Habitat Operations and Maintenance System, or HOMS. This concept involves the use of ~150 SuperBot modules in concert with each other and a few specialized tools (such as cameras and scoops). These modules, similar in all respects to the modules described in [2] and [3], are then used and reconfigured to accomplish a range of tasks on the lunar surface. For example, the same 10 SuperBot modules can be reconfigured to make an excavation arm for ISRU purposes or a small instrumented walker for habitat inspection. This use of specialized components with common docking interfaces, such as patch kits or cameras, transforms groups of identical SuperBot modules into versatile tools. We highlight here some of the tasks envisioned for HOMS in the initial stages of the second age of lunar exploration.

Logistics: The HOMS system could configure as a set of legs to move supply pallets from landed cargo elements to the outpost. HOMS could also handle possibly dangerous tasks in the resupply of spacecraft consumables, such as connecting and disconnecting external fuel lines.

Operations and Maintenance: The HOMS system is ideally suited for (1) dust mitigation, such as microwave sintering of areas (using SuperBot walkers equipped with specialized microwave modules) surrounding the habitat, (2) in-situ solar panel production (3) solar panel cleaning (using SuperBot walkers equipped with brushes), (4) real-time monitoring and inspection of habitats and landed spacecraft (using walkers equipped with cameras), (5) outpost navigational beacons (6) nuclear reactor operations and (7) repair of habitats and spacecraft. For example, HOMS could be used to inspect and refuel surface nuclear reactors, minimizing the danger to human life.

Construction: At early lunar outposts, the HOMS system in the form of multiple SuperBot walkers with scoops could be used to provide a significant regolith mass excavation capability. This would be useful for the construction of foundations, grading roadbeds, running power lines, and creating emergency radiation storm shelters for the crew.

ISRU: The HOMS system could be used to provide regolith feedstock to ISRU pilot plants on the early missions, either through a system of scoops or as legs to allow active reconfiguration of a larger modular conveyor belt system.

Conclusion: The HOMS concept has countless applications at lunar outposts. The high degree of hardware commonality between the HOMS system and the Mini-MIS, and MULE SuperBot variants [2, 3], as well as any SuperBot variants designed for orbital and cislunar operations, leverages technology development costs across a wide array of mission types while promoting ease of repair and lowering costs. The SuperBot HOMS system offers a pathway towards flexible and robust human lunar surface operations and economical lunar surface development.

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PHOBOS: A CRITICAL LINK BETWEEN MOON AND MARS EXPLORATION. Pascal Lee[1] , Stephen Braham[2], Greg Mungas[3], Matt Silver[4], Peter Thomas[5], and Michael West[6], [1]Mars Institute & SETI Institute, NASA Ames Research Center, MS 245-3, Moffett Field, CA 94035-1000, USA, plee@marsinstitute.info. [2]Simon Fraser University, Vancouver, Canada, [3]Firestar Engineering LLC & Mars Institute, [4]Massachusetts Institute of Technology, [5]Cornell University, [6]Mars Institute.

Introduction: Phobos, the inner satellite of Mars, has long been considered a possible stepping stone in the human exploration of Mars [1-8]. However, classical arguments in favor of a human mission to Phobos, which include:

- *Minimal Δv's needed to reach Phobos's surface*
- *Ability to monitor Mars from a stable platform in low Mars orbit (LMO)*
- *Ability to teleoperate robots on Mars without signif cant time delay*
- *Opportunity to advance the scientific investigation of small bodies*
- *Potential of finding H_2O on Phobos which might be used as a resource*

have generally not been compelling enough to create a broad consensus placing Phobos on the critical path of human Mars exploration. We have recently suggested that at least three additional considerations which have matured only in recent years should prompt a review of Phobos's role in human Mars exploration and should position the satellite as a critical next step following the human return to the Moon [9].

Phobos as a "Library of Alexandria" of Mars: As the Earth receives a flux of martian meteorites, Phobos's regolith might hold a record of martian crustal material of meteoritic origin, accumulated throughout Phobos's circum-martian history, having sampled Mars on a global scale, presenting possibly better preservation than even present martian surface materials which may be heavily oxidized, and thus offering possibly unique insights into Mars's geology, evolution, and possible biology. Impact velocities of martian ejecta onto Phobos are high, making survival difficult (B. Gladman, *pers. comm.*). But a preserved meteoritic record on Phobos is a possibility warranting further investigation, through both detailed modeling of impact accretion and direct robotic scouting. If confirmed, humans on Phobos would be able to significantly advance on Phobos our knowledge of Mars itself. Deimos does not present a similar potential.

Phobos as a glove box for Mars: In the context of current and anticipated planetary protection requirements regarding Mars exploration over the next decades, humans established on Phobos would be ideally positioned to teleoperate robotic scouts for an in-depth and aseptic reconnaissance of Mars [10]. A modest infrastructure established on Phobos could also be used to process/quarantine/screen returned martian samples before Earthbound forwarding.

Phobos as a catalyst for human Mars exploration: The bulk of the challenge, specific hardware development, and cost of a human mission to Mars lies in that part of the mission that brings astronauts all the way down to the martian surface, enables their surface ops, and returns them to LMO. If no human journey to Mars were undertaken before humans are ready for a landing on Mars, decades might elapse after our return to the Moon before humans walk on Mars. Phobos offers the following key *programmatic* advantages: a) it is a martian target that is technically achievable in the *immediate* wake of humans returning to the Moon requiring no or only minor adaptations of lunar hardware; b) human missions to Phobos reduce risk by offering opportunities for a stepwise build up to full-up Mars landed missions; c) Phobos enables a steady cadence of exciting, meaningful and tangible near-term missions at Mars, thus ensuring programmatic focus and continued public support.

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Lunar Power Architectures: A Power Transmission System for the Shackleton Crater

Roger X. Lenard, Gary 'ROD' Rodriguez

Abstract: *The application context is explored including the soil conditions, incident radiation, terrain of the South Lunar Pole and the Shackleton Crater. A requirement exists which would seek to provide surface power 'downhole' to the crater floor in support of extraction of water ice frozen into the local soil's matrix, an example of* in-situ *Resource Utilization (ISRU). While a microwave power beam could be a solution it is expected that the microwave energy would cause sublimation of the ice, a situation which is not responsive to mission objectives.*

A review of power transmission methods leads to the selection of a three-phase Alternating Current Delta power transmission line. One implementation scenario would bury the conductors where the terrain permits, using robotic auxiliaries to perform the installation. A method of line filtering would recover accumulated D.C. levels, A.C. noise and switching transients as 'free energy'.

A power plant scenario is presented which is a hybrid nuclear-solar furnace facility. This plant would deliver energy both day and night, and in the process would double the service life of the nuclear fuel core, improving the economics of the ISRU operation over time. The hybrid approach would employ a common power thermal-to-electric conversion system that simplifies the overall power system architecture. The reactor would maintain temperature from decay heat and would not have problems with freezing components or the shock of thermal cycling.

Keywords: *Lunar Power Architectures, three-phase transmission, delta configuration, automated deployment, regenerative line filtering, ISRU infrastructures, nuclear-hybrid power plant.*

SUPERBOTS ON THE LUNAR SURFACE: A ROBOTIC MULTI-USE LUNAR EXPLORER (MULE).
R.C.F. Lentz[1], G.J. Taylor[1], S.J. Lawrence[1], L.M. Martel[1], W.-M. Shen[2], P.M. Will[2], M.H. Sims[3], S. Colombano[3], D. Kortenkamp[4], B. Damer[5], W. Chun[6]; [1]HIGP, University of Hawaii, Honolulu, HI 96822; rcflentz@higp.hawaii.edu; [2]ISI, University of Southern California, LA, CA; [3]NASA AMES, Research Center, Mountain View, CA; [4]Metrica, Houston, TX; [5]DigitalSpace, Santa Cruz, CA; [6]Lockheed-Martin Corp, Denver, CO.

Introduction: SuperBots are modular, multifunctional, and reconfigurable robots [1]. They are an elegant example of "design for reuse" that can reduce cost and payload mass while enhancing mission performance, reliability, and safety through their ability to change shape and function as needed. Constructed of autonomous, intelligent, and self-reconfigurable modules, SuperBots can work independently or in concert to perform an enormous range of tasks [e.g. 2,3]. Our vision of a SuperBot autonomous explorer and astronaut assistant is called the Multi-Use Lunar Explorer (MULE). The fundamental idea is to set up 100+ SuperBot modules on a rover chassis and, with a few specialized tools, use and reuse these modules to accomplish a variety of geologic and resource exploration tasks on the lunar surface and subsurface, with or without the help of astronauts.

Reconfigurability of the SuperBot modules is the key to their success. MULE modules can combine in a variety of ways to perform multiple tasks during different mission stages. For example, one level of a toolbox (12 SuperBot modules) can reconfigure to make a trenching arm, which can later reconfigure to make an element of a seismic network. Only a few specialized components (e.g. scoop, geophone, cameras, etc.), built with common docking interfaces, can transform an arrangement of identical SuperBot modules into versatile tools. We highlight below some of the tasks planned for MULE as an astronaut assistant and as an autonomous explorer.

Astronaut Assistant: As a pack mule, we envision the MULE carrying the bulk of the SuperBot modules in two box configurations, one for rock sample storage and one to carry simple tools for the astronauts (rock hammer, shovels, rakes, scoops, etc.). As a deep drilling platform, we envision a specialized drill system, to help investigate the lunar subsurface, anchored to a platform of SuperBots and stabilized by SuperBot-constructed legs. To further assist in geologic and resource exploration, we envision the MULE with a scientific instrument package on board (e.g. multispectral cameras), programmable by the astronauts to carry out measurements that may need long integration times or that are in astronaut-inaccessible locations.

The MULE could also offer significant safety features for the astronauts by carrying extra air and consumables, rescuing fallen or injured astronauts, or even acting as an emergency shelter for radiation shielding.

Autonomous Explorer: The MULE would also act autonomously before astronauts arrive, after they leave, or during the mission while they are asleep. As part of exploring the lunar subsurface, we envision a shallow trenching device consisting of an arm made of SuperBot modules and a specialized terminal scoop or bucketwheel. The depth of the trench could be increased by simply adding more modules to the arm, while the trench width and length would be controlled by MULE movement. This arm could simultaneously dump scoops of regolith into an on-board ISRU experiment.

An additional scientific SuperBot project would be the deployment of a seismic geophone network. Several groups (~8) of SuperBot modules would reconfigure to form hexapods or wheels (~10 modules each), and with a specialized geophone module incorporated in each, these network elements could autonomously deploy themselves into multiple, reconfigurable lines or arrays to map the lunar subsurface [see 2 for more details].

Other MULE tasks: MULE could also perform other tasks, including: long-distance or rough-terrain mapping or reconnaissance, rock sample collection and return, E/PO teleoperation exercises for Earth-bound students, and photo-documentation (either autonomously or teleoperated) of mission events and astronaut activities for historical or artistic purposes.

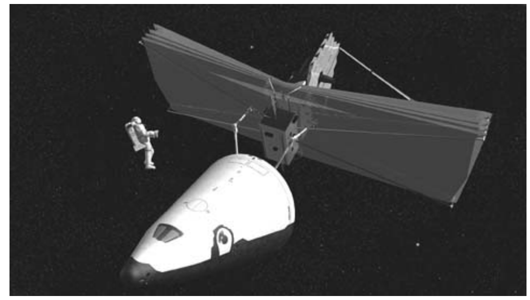
Why SuperBot MULE? SuperBots reflect a revolutionary shift from the traditional approach of building separate robots for separate tasks. Flexible and durable, SuperBot technology and design can provide (1) near-term use as a MULE astronaut assistant and autonomous explorer and (2) long-term expandability in our exploration and development of the Moon and space.

References: [1] Shen et al., this volume [2] Taylor et al, this volume [3] Lawrence et al, this volume

SERVICING THE SINGLE APERTURE FAR INFRARED (SAFIR) TELESCOPE FROM A LUNAR-EXPLORATION ENABLED GATEWAY. Dan F. Lester[1] and Charles Lillie[2], [1]Department of Astronomy, University of Texas, Austin TX [2] Northrop Grumman Space Technology, One Space Park, Redondo Beach CA.

Introduction: We consider how elements planned for human exploration of the Moon can enable other priority science goals, in particular for routine servicing and maintenance of the Single Aperture Far Infrared Telescope (SAFIR), an identified priority for the NASA Science Missions Directorate and the science community [1]. Large space telescopes like this are key components of the *Vision for Space Exploration*. This 10m-diameter space telescope operating at the Earth-Sun L2 libration point could be serviced conveniently at a “gateway” facility at Earth-Moon L1, a facility that could play an important role in lunar surface exploration. SAFIR can be considered a strawman target for in-space activity that could offer dramatic benefit to the large number of science missions for which the Earth-Sun L2 operational location is clearly optimal. We emphasize that the minimal propulsion needed for transfer between L2 and L1 render missions deployed at the former scientifically powerful but relatively human-unfriendly site to be conveniently accessible for hands-on activity. It is such free-space opportunities, rather than observatories emplanted on the lunar surface, that provide real value for the astronomy goals of the *Vision for Space Exploration*.

Background: SAFIR is a mission concept that would support far infrared and submillimeter astronomy, and could be launched as early as 2015. It would operate from 20-800 µm, essentially filling the large spectral gap between that provided by the James Webb Space Telescope and that accessible to large ground-based telescopes. At an operating temperature <10K, achieved by passive supplemented by active cooling, SAFIR would permit cosmic background-limited performance in the infrared, and provide three to four orders of magnitude improvement in sensitivity over preexisting space observatories. With this performance, SAFIR will see the formation of the first galaxies and track the star formation history of the Universe. It will also provide insights into the synthesis of biogenic molecules in proto-solar systems around young stars. While the baseline concept is one that is autonomously deployed – a concept that appears entirely achievable, it does not provide for any kind of servicing. As the technological capabilities of infrared sensors is on a steep trajectory of improvement, such servicing opportunities, in which focal plane instruments are replaced after several years, could be strongly enabling scientifically.



SAFIR Servicing at an L1 “Gateway”: We have evaluated [2,3,4] opportunities for SAFIR servicing, and find one of these to be especially promising. After returning from Earth-Sun L2 to Earth-Moon L1, human and robotic servicing of the observatory can be carried out efficiently by humans and robots at a gateway installation there. As has been reported on by Thronson et al. in this conference, and studied extensively by NASA, such a gateway facility could host such an observatory along with other facilities of interest to space astronomy, lunar surface exploration, as well as voyages to Mars, in a shipyard scenario. Accessed by the CEV after cycling of the observatory to ambient temperature, it could function as a base of operations with which to manage maintenance (perhaps even to rescue a faulty deployment) of SAFIR in the mode of that for the Hubble Space Telescope. Such capability would allow reuse of major technical investments, such as the telescope itself, but would require careful design such that critical subsystems would be replaceable with in-space operations. The gateway would need to be equipped with crane and grapple fixtures, perhaps EVA capabilities as well as host robotic agents that could be controlled with low latency from the site. Rendezvous and docking systems would also be required, as would contamination mitigation. As an extension of our *SAFIR Vision Mission Study*, funded by the Science Mission Directorate, we have considered the risks and benefits of such a servicing strategy, and compared the requirements with likely resources that would serve needs for lunar surface exploration.

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SEARCH FOR WATER ICE IN THE MOON COLD TRAPS (POLAR CRATERS) WITH LUNAR EXPLORATION NEUTRON DETECTOR ONBOARD LRO MISSION M.L. Litvak[1], V.V Shevchenko[2] and LEND/LRO Instrument Team, [1]Space Research Institute, RAS, Moscow, 117997, Russia, max@cgrsmx.iki.rssi.ru, [2]Stenrnberg Astronomical Institute/Moscow State University, Moscow, Russia

Introduction. The Lunar Exploration Neutron Detector (LEND) has been selected for Lunar Reconnaissance Orbiter mission to determine hydrogen distribution through lunar subsurface of 1-2 meters with high sensitivity and spatial resolution [1]. It is known that presence of hydrogen atoms in lunar regolith significantly influences on the epithermal neutron leakage flux allowing measurements of hydrogen content. For neutron detectors without imaging capabilities the surface footprint of such measurements is defined by the orbit's altitude and may be as large as 50 km x 50 km (50 km is an averaged LRO altitude). That is why the development collimator for the detection of epithermal neutrons is suggested (LEND) in terms to improve spatial resolution [1,2]. Due to efficient collimation of epithermal neutrons, LEND is able to provide observation of hydrogen content with spatial resolution up to 5 km and detection limit better then 100 ppm in vicinity of lunar poles. LEND will make possible to get new information about shadowed polar craters (cold traps) where water ice may be accumulated from impact episodes with comets and preserved until the modern time.

In this presentation we focus on identification of possible Lunar polar cold traps, as targets of LEND investigation, and on the estimation of instrument detection limits of Hydrogen deposits for them.

Data Analysis. To perform such analysis, the two sets of lunar craters were selected for the northern and southern polar regions of Moon (Fig 1). The center positions of southern cold traps lie within 83.3S-89.9S latitude belt. Their shadowed surfaces range from 30 up to 575 km^2. The northern cold traps have centers located within 81.5N-89.2N latitude belt and their shadowed surface range from 30 up to 300 km^2.

The optimized shape of collimator has been used to perform numerical estimations of counting rate in the LEND detectors (see [2]). Such collimator allows to achieve 82.5 ppm Hydrogen detection limit for the hypothetical spot with radius 5 km centered at the lunar poles [2]. The detection limits for amount of Hydrogen at each given cold trap were found as 3σ difference between counting rates observed above the target with the cold trap and above surrounding dry regolith.

Results. The table 1 contains the results of numerical simulation of the LEND detection limits in terms of search of Hydrogen content inside lunar cold traps. The 8 most detectable regions are presented in this table including three northern and five southern targets. It seen that LEND will be able to detect the presence of Hydrogen ranges from 30 up to 150 ppm for the selected cold traps.

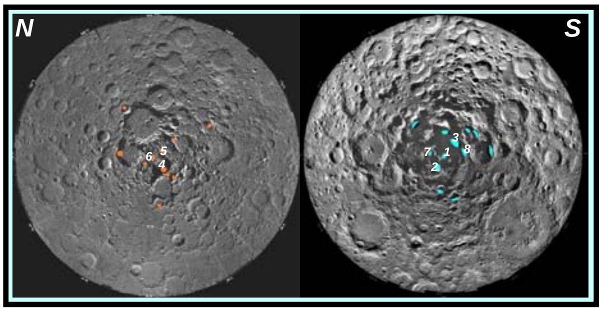

Fig. 1. Distribution of Moon cold traps in the northern (red dots, left map) hemisphere and southern hemisphere (cyan dots, right map) taken from [3]. The selected regions 1-8 correspond to the best Hydrogen detection limit (see Table 1).

Table 1. Results of numerical simulation of LEND detection limit concerning search for Hydrogen content inside cold traps.

LEND Candidate Targets with Water Ice Deposits	LEND Hydrogen detection limit level (in ppm)
No.1: Crater at (89.9 S, 111.1E) with area of 380 km2	30.9
No.2: 88.5 S 220.0E 400 km2	75.8
No.3: 87.6 S 38.0E 580 km2	80.1
No.4: 88.6 N 32.0E 170 km2	113.8
No.5: 89.2 N 122.5E 110 km2	121.8
No. 6 89.0 N 291.2E 148 km2	135.5
No. 7 88.4 S 260.2E 145 km2	141.3
No. 8 86.8 S 75.8E 257 km2	151.5

References: [1] Mitrofanov I.G. et al. this issue, (2005). [2] Sanin A.B. et al., this issue (2005)

LUNAR AGGLUTINITIC GLASS SIMULANTS WITH NANOPHASE IRON. Yang Liu[1] (yangl@utk.edu), Lawrence A. Taylor[1], James R. Thompson[2], Allan Patchen[1], Edward Hill[1], Jaesung Park[1]; [1]Planetary Geosciences Institute, Department of Earth & Planetary Sciences, Univ. of Tennessee, Knoxville, TN 37996; [2]Oak Ridge National Lab, Oak Ridge, TN 37831-6061 and Department of Physics, University ot Tennessee, Knoxville TN 37996

Introduction: The adhering, abrasive, and pervasive nature of lunar dust presents many problems for ISRU and dust mitigation on the Moon [1]. Lunar soil contains a significant amount of agglutinitic glass (up to 50 wt%, [1, 2]) containing nanophase (np) Fe^0 (np-Fe^0, Fig. 1a), which is formed by micrometeorite impact-induced melting, vaporization, and deposition [3-5]. The presence of np-Fe^0 generates the observed magnetic susceptibility of lunar soil [1, 2, 5]. Recently, a startling and new discovery by Taylor and Meek [6, 7] revealed that a portion of lunar soil placed in a normal 2.45 GHz microwave oven will melt at >1200 ^{0}C before your tea will boil at 100 ^{0}C, caused by np-Fe^0. The magnetic properties of lunar soil are also important for dust mitigation on the Moon [e.g., 1]. Due to lack of availability of lunar soil, material simulating these lunar soil properties is required for testing different mitigation methods using electromagnetic fields. In addition, simulant with np-Fe^0 in metastable glass is also necessary for toxilogocal studies.

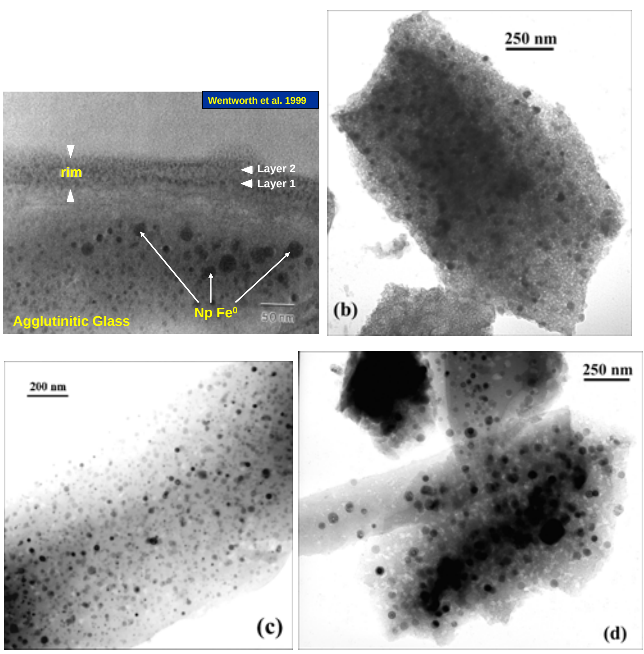

Fig. 1. TEM image of lunar agglutinitic glass (a) and the simulants (b-d). (b) shows simulant LAG-B and those in (c) and (d) are LAG-S.

Results: We have developed a new method for successfully synthesizing silicate glass containing uniformly dispersed np-Fe^0 (Figs. 1 & 2). The advantage of this method is that the composition of the amorphous silicate glass can be controlled. Two types of simulants have been prepared: LAG-B (Fig. 1b) with ~60 wt% SiO_2, ~8 wt% Al_2O_3, ~10 wt% CaO, and ~8 wt% MgO, ~ 10 wt% FeO^T (Fe^0 and Fe^{2+}), and LAG-S (Fig. 1c-d) with ~90 wt% SiO_2 and ~10 wt% FeO^T, as determined by electron microprobe. The composition of LAG-B is similar to the agglutinitic glass [2]. Powder samples were checked with a Siemens D500 X-ray diffractometer (XRD). The XRD spectra (e.g. Fig. 2) of the simulants contain metallic iron and olivine. Images obtained with a Hitachi H-800 Transmission Electron Microscope (TEM) show that the Fe^0 particle is mostly ≤50 nm (e.g. Fig. 1b-d). SQUID magnetization measurements on LAG-S, with its 50 nm Fe^0, show a dominant ferromagnetic response, with an additional magnetic susceptibility component attributed to ionic Fe.

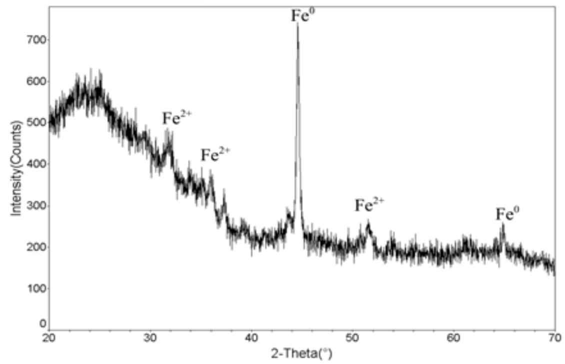

Fig. 2. XRD spectrum of the simulant LAG-B. The broad peak at left hand side is the signal of the amorphous silicate.

It will be necessary to add this agglutinitic glass simulant to other lunar soil simulants (e.g., JSC-1A) in order to actually produce the desired bulk chemical, texture, magnetic, and microwave coupling properties for use in appropriate ISRU experimentation.

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DEVELOPMENT OF SELENOLOGICAL AND ENGINEERING EXPLORER (SELENE). Hironori Maejima[1], Susumu Sasaki[2] and Yoshisada Takizawa[3] , Japan Aerospace Exploration Agency, [1, 3]2-1-1 Sengen, Tsukuba, Ibaraki, 305-8505, JAPAN, [2]3-1-1, Yoshinodai, Sagamihara, Kanagawa, 229-8510, JAPAN, [1]maejima.hironori@jaxa.jp, [2]sasaki@isas.jaxa.jp, [3]takizawa.yoshisada@jaxa.jp

Introduction: SELENE (SELenological and ENgineering Explorer), has been developed by JAXA, is currently planned to be launched by an H-IIA launch vehicle in 2007. The major objectives of the mission are to obtain scientific data on lunar origins and evolution, and to develop the technologies for future lunar exploration. The scientific data will be also used for exploring the possibility of future utilization of the Moon.

Mission: SELENE, a large and complex lunar exploration mission in the post-Apollo era, will consist of three separate lunar satellites; a main orbiter, a small relay satellite, and a small Very Long Baseline Interferometry (VLBI) astronomy satellite called VRAD. The main orbiter will maneuver to a 100-km circular orbit and have many instruments to carry out observations, including global mapping of the lunar surface and lunar magnetic field. The orbiter will link up with the relay satellite and VRAD satellite to study the lunar gravitational field. Other mission objectives are to demonstrate technologies for injection into lunar transfer orbit and lunar orbit, the orbit transition, and attitude and orbit control. It is expected that SELENE instruments will provide us with valuable scientific outcomes, as well as information and data useful for future lunar explorations. Scientific missions are categorized into followings;

(1) Science of the Moon: The Moon has been observed and explored extensively as the most familiar body. Although the Moon is more thoroughly studied than any other planetary bodies in the solar system, its origin and evolution process are still controversial. The SELENE mission targets are the global characterization of lunar surface and detai1ed gravimetry. This mission will provide globally the high-quality and high-resolution data on element abundance, mineral assemblage, surface topography, sub-surface structure, magnetic and gravity field, and precession. We aim to better understand the origin and evolution of the Moon by these observations.

(2) Science on the Moon: The SELENE mission investigates energetic particles, electromagnetic field, and plasma around the Moon. The measurements of the lunar environments are highly valuable scientifically, and also provide important information for the future human activities on the Moon.

(3) Science from the Moon: The SELENE orbiter provides unique opportunities to study the earth's plasma environments. Imaging of the earth in the wavelength from extreme ultraviolet to visible radiation will contribute to clarifying the global dynamics of terrestrial plasma-sphere. The radio waves from the Jupiter and the Saturn are observed in the low noise environment of the Moon. The topographic study of the polar region will also provide the basic information of future construction of the astronomical observatory on the lunar surface.

Figure 1 Image of SELENE orbiting the Moon

Ground Systems:

SELENE Operation and Analysis Center (SOAC) will be facilitated for this project at Sagamihara Campus, JAXA. SOAC integrates Tracking & Control system, Mission Operation System and Data Archive & Analysis system, which enable efficient mission operations.

Development Status:

Flight components were integrated at Tsukuba Space Center, JAXA. Integrated electrical performance test was completed with no major problems. It will be followed by final integration tests and shipped to Tanegashima Space Center for launch campaign.

SOAC is presently under the integration test. Compatibility test with the spacecraft, ground data system test, and end-to-end test will be conducted in the near future.

Risk Assessment of ISRU in Lunar Base Mission Scenarios Trygve "Spike" Magelssen[1], [1]Futron Corporation 7315 Wisconsin Ave. Suite 900W, Bethesda, MD 20814-3202. e-mail: trygve@space.edu, Steve Hooker[2], [2]Futron Corporation 7315 Wisconsin Ave. Suite 900W, Bethesda, MD 20814-3202. e-mail: shooker@futron.com.

Introduction: Risks, involved in lunar base mission development and realization, start from the very inception of the idea and last well after the mission has been completed. Resultant activities of Space programs and governments as well as the financial, political, technical, and environmental impacts, of the risks taken, are affected by what is decided and acted upon in the course realizing the chosen missions. Where the course of human destiny and the direction the Space program goes is predicated on the decisions and risks assumed by the missions selected, the financial resources spent, the political support enjoined to the missions, and the technological advances that come from such endeavors. The legacy of information garnered from the Apollo missions enables us to envision greater possibilities in exploration, science, and to have a greater depth of understanding of what is be needed next to find out more about how to fully realize what we don't yet know about the space exploration, terrestrial planets, and the Moon [1].

Lunar base mission scenarios of various types will utilize a diverse set of technologies dependent upon the construct and purpose of the lunar bases. Along with the diversity of the technologies comes a level of criticality of how much that technology influences the mission scenario and future missions in Space exploration. It is and has been recognized that In-Situ Resource Utilization (ISRU) will play a predominant role in Space exploration to the Moon, Mars, and beyond [2]. Design and development of the ISRU equipment and processes, for lunar base development and operations, will be extremely challenging. The decisions regarding and the use of ISRU technologies will determine the extent of feasibility and success of the lunar base missions and will influence the course of human Space exploration as well [2].

ISRU lunar base mission scenarios require Critical Enabling Technologies (CETs) that are specific to the ISRU mission and will be more complex in design and construct than missions that rely solely upon Earth support. Yet, the use of in-situ resources is be the only way to fully realize cost-effective, self-sufficiency of lunar base development and operation [3]. Considerations for mission success include: technology selection, funding reserves and incoming revenues, management experience and flexibility, personnel preparedness and readiness, and return on investment for the investors and those supporting the missions, namely the government, taxpayers, and private / commercial interests waiting for the opportunities to be revealed. The risks and benefits involved in ISRU for lunar base missions are considered in this study to assess those risks and the benefits derived from the use of in-situ resources and the ISRU technologies of lunar base missions and how that may impact future Space exploration.

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AN OXYGEN PRODUCTION PLANT IN THE LUNAR ENVIRONMENT: A VACUUM PYROLYSIS APPROACH. J. P. Matchett[1], B. R. Pomeroy[2], and E. H. Cardiff[3], [1]USAF/NASA GSFC Building 11 Room C112 Greenbelt, MD 20771 John.P.Matchett@nasa.gov, [2]Brian.R.Pomeroy@nasa.gov, [3]Eric.H.Cardiff@nasa.gov

Introduction: The engineering design for *in-situ* production plants must meet operational requirements while overcoming the challenges of working in the lunar environment. These mission requirements can be grouped as environmental, performance, and programmatic requirements. It is anticipated that the technology readiness of an oxygen production plant will first be demonstrated by a small sample test on the moon, followed by a demonstration plant capable of producing five kilograms of oxygen in a period of eight hours. Finally, a pilot plant will be built to support continuous oxygen production when sunlight is available. These missions, specifically for a vacuum pyrolysis implementation, must fulfill the following requirements.

Mission Requirements: *Environmental*. The complexity of the lunar environment presents new engineering challenges to a terrestrially proven pyrolysis system. The lunar environment is characteristically under high vacuum (10^{-9} to 10^{-12} Torr), having operational temperature ranges from 100 to 400 K, with smaller gravitational forces. Systems require protection from micrometeorite impacts, as well as higher solar fluxes, including cosmic rays, solar wind and possible flares [1,2].

Performance. Operational lunar regolith processing facility designs must meet strict performance metrics for implementation with system mass as one of the most limiting criteria. A vacuum pyrolysis plant requires a pyrolysis chamber, condenser, cryocooler, mobile regolith collector, storage containers, power supply, control monitoring equipment, and maintenance equipment. This comprises an estimated half the mass of a comparable ilmenite reduction by hydrogen plant [3].

System power can be potentially provided by solar cells or by an outpost nuclear reactor. Several techniques, including the vacuum pyrolysis technique, and even possibly the ilmenite reduction technique, can take advantage of the plentiful solar flux as a heat source to reduce power requirements. Operations of any lunar system that uses solar energy as power will be limited to periods of continuous flux, which limits annual production yield by half.

Oxygen production yields are estimated at 6-23% of regolith mass depending upon oxide dissociation and condenser efficiency [4].

Secondary uses of the oxygen production to produce either volatile gasses, or useful slag, can further enhance the usefulness of the plant. Vacuum pyrolysis may have favorable secondary uses including the forging of molten regolith slag into structural elements, and possible isolation of hydrogen and helium from solar wind.

A key aspect of the performance of the plant is the resupply needs from Earth, both in terms of servicing and consumables. No consumables are required outside of system maintenance for the vacuum pyrolysis technique, but this may be counterbalanced by an increased rate of maintenance due to higher system temperatures.

Programmatic. Key programmatic requirements for evaluation include complexity, reliability, technology readiness level, cost, and scalability. An oxygen production plant by vacuum pyrolysis has minimal complexity when compared to other *in-situ* utilization methods. The process is simpler because far fewer reactions take place to produce gaseous oxygen. Only heating, cooling, and gas transport systems are required. The high temperature environment poses contamination problems to the system [2].

The system's reliability is yet to be fully understood; however, many of the system's processes, including vacuum distillation and thermal distillation, are currently used in terrestrial industry. Therefore, the technology readiness level of the vacuum pyrolysis technique is lower than the ilmenite reduction technique, but high enough to develop for upcoming missions. Recent work accomplished at NASA Goddard Space Flight Center has advanced the technique, demonstrating the ability to vaporize lunar regolith and to produce gaseous oxygen. The cost of the vacuum pyrolysis system is competitively less than that of other systems due to its low system mass and low power requirement.

Conclusion: An oxygen production plant through vacuum pyrolysis has been proposed to achieve certain performance metrics while minimizing system cost and mass. Further study of the method itself is necessary to better understand the methods application to a full-scale plant design.

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JAPAN'S MOON EXPLORATION - FIRST LUNAR RESOURCES UTILIZATION WORKSHOP

Kai Matsui[1], Shigeru Aoki[2] and Yoshisada Takizawa[3] Japan Aerospace Exploration Agency, SENGEN 2-1-1, TUKUBA, IBARAKI 305-8505 JAPAN. matsui.kai@jaxa.jp[1], aoki.shigeru@jaxa.jp[2], takzawa.yoshisada@jaxa.jp[3]

Introduction: The Japan Aerospace Exploration Agency (JAXA) unveiled its 20-year plan called "JAXA 2025 Vision" in April 2005, in which five priorities were set for the next wave of space programs. One of the proposed agendas is to build a lunar base and populate it with advanced robotics by around 2025. The idea is more than a pipe-dream; over the next decade, JAXA would develop robotic landers for surveys of the moon, and would acquire technological capability to enable the extended human presence on the moon and to play a role as "an equal partner" in international projects by the first quarter of the 21st century.

JAXA has been strategizing the best way to bring the ambitious plan to reality. As a first step to achieve the ultimate goal, a series of robotic missions will be performed to collect in-situ information and demonstrate the maturity of relevant critical technologies.

In-Situ Resource Utilization (ISRU) would be crucial to the success of manned lunar missions as ISRU-derived materials would replace those that otherwise would have to be hauled from Earth. Accordingly, it is desirable that studies should be conducted on feasibility and availability of ISRU-related technologies at an early stage, thereby determining possibilities for use of space resources.

Workshop result: To blueprint a lunar exploration scenario, technological issues to overcome should be identified at each of the following five phases: (1) remote sensing, (2) in-situ exploration, (3) ISRU technology demonstration, (4) lunar oxygen pilot plant, and (5) human lunar base.

Lunar Resources Utilization Study Group was formed in October 2004, consisting of three working groups for remote/in-situ sensing, resources collection, and resources processing.

With technological issues screened out by each group, three working groups had a first formal meeting and discussion in May 2005 and Lunar Resources Utilization Workshop was held at the end of July. The workshop marked the first forum where opinions and information were exchanged with a focus on extraction and collection of water and oxygen which are ISRU products critical to support human presence on the moon. Technical issues identified by each working group are as follows.

The sensing working group examined technical issues in both remote sensing and in-situ sensing mission. For remote sensing mission, a focus was on creating maps of water ice, permanent polar shadow/sunshine areas and mineral distribution (Fe, Ti, etc.), and digital elevation model of lunar poles, with use of processed SELENE data. For in-situ measurements, scientific instruments mounted on lander and rover, such as X-ray spectrometer, gamma-ray spectrometer, multi-band cameras and mass spectrometer are the major topic for the discussion. In addition, a mission scenario was examined on measuring physical parameters of lunar regolith.

The resources collection working group identified issues pertaining to measurements of physical properties and mining and sampling of lunar regolith. Specifically, a focus was on (1) inherent parameters or physical properties in lunar regolith composition, (2) characterization of regolith, (3) chemical properties of the regolith, (4) interaction of regolith-mechanical systems, and (5) design of mechanical system.

The resources processing working group examined in-situ processes of oxygen production from lunar minerals, such as ilmenite, pyroxene, basalt, and anorthite. The reduction products/approaches were evaluated in terms of (1) the selection of process, (2) equilibration, (3) kinetics, and (4) system design.

Based on the identified technological issues, a roadmap was developed so as to prioritize the development of technologies to enable future lunar missions, with significant consideration given to the maturity of existing technology available in fulfilling the requirements in five phases above described.

Future plans call for us to examine other aspects, such as energy, robotics, resources storage, economics and space law.

LOW TEMPERATURE MOLTEN SALT ELECTROLYSIS FOR OXYGEN PRODUCTION FROM LUNAR SOIL. Mishra, B., Duke, M., Olsen D.L., Roubidoux, J., McDermott, J., Tordonato, D.

Production of oxygen gas from lunar resources is key to sustainable space exploration. The process for oxygen production must be robust, energy efficient, self-sustained, automated and with adequate capacity. A low temperature process that can produce pure oxygen directly in one step, therefore, can be very attractive. Molten salt technology allows the establishment such a process with minimal dependence on terrestrial resources. This paper will present the advantages and disadvantages of several molten salt-based processes that are capable of producing oxygen. Four schemes will be discussed that are inherently different but use molten material and electrolysis. (1) Electronic reduction of solid lunar regolith; (2) Dissolution of regolith in molten salt solvent and solution electrolysis; (3) Metallothermic direct reduction of soil by calcium and electrolysis of dissolved calcium oxide; (4) Low temperature ionic liquid dissolution of regolith and solution electrolysis. In each of these processes oxygen gas is directly produced anodically. Results will be presented on two of these processes.

LUNAR EXPLORATION NEUTRON DETECTOR ONBOARD LRO MISSION I.G. Mitrofanov[1] with LEND/LRO Instrument Team, [1]Space Research Institute, RAS, Moscow, 117997, Russia, *imitrofa@space.ru*

Introduction. The Russian-made, Russian-supplied instrument LEND (Lunar Exploration Neutron Detector) is young brother of another Russian instrument HEND (High Energy Neutron Detector), which continues to perform well in its fifth year of science measurements onboard NASA's Mars Odyssey [1]. LEND and HEND have similar types of neutron sensors, and valuable science data from HEND about Martian water resources has proved adequate selection of these sensors for purposes of orbital "neutronography" of the planet.

The Lunar Exploration Neutron Detector (LEND) has been selected for Lunar Reconnaissance Orbiter mission to provide the global search of hydrogen distribution through 1-2 meters of lunar subsurface from 50 km circular polar orbit of LRO [2].

Instrumentation. The most important property of LEND is its capability to provide high spatial resolution mapping of epithermal neutrons with collimated neutron detectors (see detectors ***A*** in Figure 1). LEND is able to detect hydrogen-rich spot at a pole with 100 ppm of hydrogen with spatial resolution of 5 km (Half Width Half Maximum) and to produce global mapping of hydrogen content with resolution of 5-20 km [3]. If hydrogen is associated with water, detection limit of 100 ppm of hydrogen corresponds to ~0.1 wt% of water in the regolith.

Neutron radiation from the regolith could have as large an impact on astronaut safety as energetic charged particles from Galactic Comic Rays and Solar Particle Events. LEND will have a full set of sensors for thermal (***B*** and ***C***), epithermal ***(D)*** and high energy neutrons (***E***) to provide data for neutron component of radiation environment in the broad range of more than 9 decades of energy (see Figure 1).

The primary type of LEND sensor is ^{3}He counter, which is used for LEND detectors ***A, B, C*** and ***D***. The ^{3}He nucleus has one neutron less than the main isotope of Helium, and it has large cross section to capture neutrons in the reaction $n + {}^3He \rightarrow {}^3H + p + 764$ keV. The Cd shield around ***A*** and ***D*** absorbs all neutrons with energies below ~0.4 eV, which exclude from detection all thermal neutrons. The major difference of LEND in comparison with HEND is collimation of neutron flux before detection. Collimating modules around ^{3}He counters ***A*** (Figure 1) effectively absorb neutrons that have large angles with respect to the normal to the surface of the Moon and provide high spatial resolution of LEND for mapping of the lunar surface. . This method of "neutronography" of another planet with high spatial resolution will be used for the first time.

The second type of LEND neutron detector is sthylbene scintillator ***E*** (Figure 1), which produces a flash of light each time a high energy neutron in the range 0.3 – 15.0 MeV collides with a hydrogen nucleus and creates a recoil proton. Special electronics distinguishes protons from electrons, and active anti-coincidence shield eliminates external charged particles.

Expected Results. Pioneering detection of lunar gamma-rays was performed in April 1966 on Soviet lunar orbiter Luna-10 [4]. James Arnold, Albert Metzger, Jacob Trombka and colleagues made the first spectral measurements of lunar gamma-rays from Apollo in 1971 [5]. First global mapping of neutron emission from the Moon was performed in 1998-99 [6] using omni-directional Neutron Spectrometer on NASA Lunar Prospector. It was found [6] that emission of epithermal neutrons decreases in polar regions of the Moon in comparison with lower latitudes.

Data from LEND with high spatial resolution could help to distinguish polar spots with enhancement of implemented hydrogen in the regolith from cold traps with water ice deposits [7]. The most conclusive results from the reconnaissance of lunar hydrogen or/and water resources would come from the joint analysis of all mapping science instruments onboard LRO taken together: Diviner, LAMP, LEND, LOLA and LROC (see [2]).

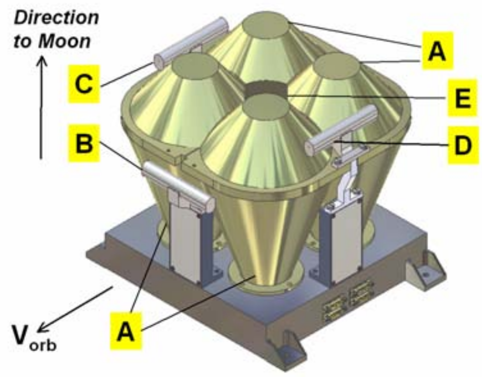

Fig. 1. Schematic view of Lunar Exploration Neutron Detector for NASA Lunar Reconnaissance Orbiter.

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INTEGRATED MARS IN-SITU PROPELLANT PRODUCTION SYSTEM. Anthony Muscatello, Robert Zubrin, Claire Ohman, and Sam Booth, Pioneer Astronautics, 11111 W. 8th Ave., Unit A, Lakewood, CO 80215, tony.muscatello@pioneerastro.com.

Introduction: Although it has a high leverage in the production of rocket propellant for the exploration of Mars, the Sabatier-Electrolysis Process (S/E) suffers from the disadvantage of producing only half of the oxygen needed to fully burn all the methane fuel produced. This situation leads to the need to either discard half the methane or, more realistically, add a second process to make more oxygen, such as carbon dioxide electrolysis or the Reverse Water Gas Shift process (RWGS). Integrating the S/E and RWGS processes into a single unit would greatly reduce equipment mass and complexity.

Accomplisments: The goal of the six-month NASA SBIR 2005 Phase I Integrated Mars In-Situ Propellant Production System (IMISPPS) project was to establish the feasibility of converting carbon dioxide and hydrogen to methane/carbon monoxide fuel according to the reaction:

$$3CO_2 + 6H_2 \rightarrow CH_4 + 2CO + 4H_2O.$$

The enthalpy of the combined reaction is exothermic at -22 kcal/mol.

As desired, the process produces oxygen in the proper ratio for use in Mars Sample Return missions or human Mars missions. A Phase II project would build a prototype flight unit. The purpose of the Phase I research was to design and build a machine for converting carbon dioxide to methane and carbon monoxide fuel using a combined Sabatier/Reverse Water Gas Shift (S/RWGS) reactor, and enough oxygen to oxidize the fuel as rocket propellant. The IMISPPS process allows the production in a single unit of all the rocket propellant needed for a Mars sample return mission or human missions using *in-situ* resource utilization to make bipropellant for Earth return. The amount of CO can be tuned to improve the specific impulse of the methane fuel. An additional goal was to investigate the feasibility of converting the CH_4/CO product to higher hydrocarbons with lower hydrogen content to reduce the amount of hydrogen imported from the Earth. Although some small conversions were found with various catalysts, none were deemed practical for Phase II investigations.

The research completed in this project included:

- Literature reviews to determine the current status of RWGS and methane/carbon monoxide conversion technology; preparation of catalysts based on the literature review results;
- Testing of the catalysts on a small scale to determine their activity;
- Scale-up of successful catalysts and previously known Sabatier and RWGS catalysts in a full scale brassboard reactor to make CH_4/CO fuel with a total propellant production rate of ~1kg/day;
- Recycling of the unreacted CO_2 and hydrogen to effect near complete conversion;
- Demonstration of electrolysis to recycle hydrogen and produce oxygen oxidizer;
- Investigation of methods such as temperature variation to modify the CH_4/CO ratio; and
- Scouting experiments into cryogenic distillation to remove CO from CH_4/CO product.

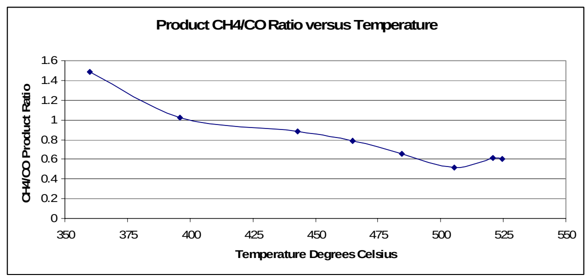

Figure 1. CH_4/CO Product Ratio versus Temperature

We prepared active RWGS catalysts, but chose to combine previously established Sabatier and RWGS catalysts that were adequate to make the CH_4/CO fuel. We scaled up the system and produced $CH_4/CO/O_2$ at rates approaching the goal of 1 kg of bipropellant per day with a leverage up to 20. We determined that reaction temperature can be used to vary the CH_4/CO ratio (Figure 1), thus allowing optimization of how much oxygen is produced. The recycling system allows near complete conversion of CO_2 and H_2 feed to fuel and oxygen. Cryogenic distillation of the CH_4/CO product is effective in removing excess CO from the CH_4, resulting in a fuel with an improved Isp.

This project has successfully demonstrated the feasibility of the S/RWGS process, showing that an integrated system could be used for a Mars Sample Return mission or human missions to Mars.

Acknowledgement: This work was conducted under NASA Small Business Innovation Research (SBIR) Funding. William Larson was the NASA KSC Contracting Officer's Technical Representative (COTR).

Modeling and Analysis of the Interactions in a Space-Based Economy. James A. Nally, Dr. Narayanan Komerath, School of Aerospace Engineering, Georgia Institute of Technology, James Austin Nally; gtg959h@mail.gatech.edu, narayanan.komerath@ae.gatech.edu

The central hypothesis of this paper is that up-front planning of the interactions between various concepts for space-based businesses, will lead to a large improvement in the business plans for all concepts. The effort reported in the paper is to quantify this hypothesis using business modeling tools, and develop the capability to properly explore the hypothesis.

An econometric model is designed to simulate an independently sustaining, space based economy. Such a model is intended to bridge the current gap between space proponents and capital rich groups looking for investment opportunities. With an increase in private sector interest, governments may be more inclined to offer reassurance on large scale investments through economic support and policy. Thus, the space industry may be revived by positive investment and consequential competition.

In order to develop the model for a space based economy, a foundation of industries is established and preliminary interactions between them are investigated. Nine “core” industries are included in this foundation: transportation, energy, tourism, mining, science, communications, military, maintenance, and delivery services. Each industry contains individual processes, whose components are linked with other processes in order to build a complex interaction structure. At this point in development, the economy will owe a majority of its growth to space-based interactions, though residual interactions still remain with Earth-based industries or markets. With the help of dynamic modeling software, the preliminary economy is designed and analyzed. Each project is isolated and then analyzed in order to determine the total project costs and minimum investment requirements. With cost structures established and baseline investment numbers available, the intention is to determine how the project costs, overall capital, and the government funding required would decrease as inter-industry interaction increases. A graphical model helps to present the result of iterative interactions in the process cycle for each industry. As the related costs and risks shrink and return rates increase, the feasibility and marketability of each of the projects increases. With the “core” economy in place, subsidiary industries are included and provide a secondary structure of interactions. This is the projected point where the space-based economy has become self sustaining and Earth interactions become relatively minor. Again, each core industry is analyzed and the resultant changes in related statistics are noted. The secondary industries are also examined and their associated costs and return schedules are diagramed.

Central to this research is the theory of interactions or supply and demand optimization, as well as several econometric forecasting variables. Each interaction in the model is constrained by minimal costs, minimal time requirements, maximum productivity, and maximum profit (in order to model an efficient economy). Optimization software is used to determine the best route in cases that external inputs or services are required in a process by subjecting the possibilities to the aforementioned constraints. Once the most favorable route is determined, it is integrated into the model. As the model takes shape, several econometric forecasting techniques are used such as internal rates of return, net present values, and weighted average costs of capital in order to determine the total project costs, minimum investment requirements, and fairly accurate predictions as to the likelihood of private sector participation. Though such predictions may prove to be somewhat biased at this point (mainly due to the lack of involvement in the space industry), they provide a conservative approach to estimate the level of industry participation and investment interest. The results of the forecasting variables are constrained at the minimum values for which contemporary projects have been funded and completed.

Thus, the independent space-based economy is modeled and its associated interactions are outlined in order to reduce associated costs. With such reductions in cost, there will be comparative increases in returns on investment, and lowered capital risk. These incentives appeal to most investors, leading to the industrialization and commercialization of space.

The Importance of Establishing a Global Lunar Seismic Network. C. R. Neal[1], [1]Dept. Civil Eng. & Geological Sciences, University of Notre Dame, Notre Dame, IN 46556, USA [neal.1@nd.edu].

Introduction. Lunar seismicity is about equal to that of intraplate earthquakes, including those that have been catastrophic [1]. Data from the Apollo seismic network continues to yield information regarding seismicity, structure, and the lunar regolith [2-8]. This paper builds upon the work of [9].

Four types of Moonquakes occur [3,10]. **1) Deep Moonquakes** – the most abundant type with >7,000 events recognized [5,6,11] originating from 700-1,200 km depth. These small-magnitude events (<3) are strongly associated with tides [3,10] and originate from specific locations (nests). To date, 318 nests have been identified [6]. **2) Thermal Moonquakes** – much smaller in magnitude than 1). Recorded events originated from many isolated locations within a few km of each Apollo seismic station [12], occurring at regular monthly intervals. The highest activity occurred 2 days after sunrise probably triggered by thermoelastic stresses at the lunar surface. **3) Shallow Moonquakes** – the strongest type, with the 3 largest ones recorded being >5 magnitude [9,13-15]. Exact focal depths are unknown because all recorded events were outside the limited network. Indirect evidence [15] suggests depths between 50-200 km. They are not correlated with tides but may be associated with boundaries between dissimilar surface features. **4) Meteoroid Impacts** - while most of the energy of an impact is expended excavating a crater, some is converted to seismic energy. Between 1969-1977, >1,700 events representing meteoroid masses of 0.1-100 kg were recorded. Events generated by smaller impacts were too numerous to be counted [12,16].

Relevance of Moonquakes. 2 types of moonquakes pose hazards to a long-term Moon base: shallow moonquakes and those caused by meteoroid impacts. [Note: although seismicity generated by the latter should not threaten any structure, a direct impact most certainly would.] Only 28 shallow Moonquakes were recorded in 8 years but they contain greater energy at high frequencies than earthquakes of comparable total energy. While surface waves are more scattered due to the nature of the regolith and prevent efficient long-range propagation, lunar seismic waves are much less attenuated than in Earth [17] so the effects of a shallow moonquake will still be felt much further than a comparable earthquake. The lack of global coverage by the Apollo seismic network has left many unknowns. For example, shallow moonquakes can be of sufficient magnitude (>5) to cause moderate structural damage (on a terrestrial scale). The effect of a >5 magnitude quake on a Moon base could be catastrophic. Currently, we do not know the causes or locations of these moonquakes. Furthermore, sites of meteoroid impact recorded between 1969-1977 are unpredictable. A direct hit from a body >0.1 kg would be catastrophic.

Need for a Global Lunar Seismic Network. This is required to locate the origins of the different types of moonquakes, especially those that could compromise a Moon base. **1)** A statistical analysis of meteorite impact sites is required to determine if the Moon base site has a statistically low probability of receiving a sizeable meteoroid impact. **2)** Understanding the nature and location of shallow moonquakes is required so the Moon base site is not in a seismically active area. These examples are prudent in terms of safety and to protect the required investment.

Required Technological Advances. An international group of scientists has been investigating the challenges of establishing a global **Lu**nar **Se**ismic **N**etwork [18-20] through the **LuSeN** mission. A modest network requires 8 seismometers (preferably 10) to be deployed around the Moon and be active for 5-7 years. Soft and hard landing options have been explored. Both have their limitations, which require technological advances in 3 inter-related areas: 1) Deployment - mass must be reduced through hardware miniaturization; 2) Hardware - needs to be more robust such that the mass required for deployment can be reduced; 3) Power - development of robust mini radionuclear thermoelectric generators (RTGs) that can maintain a power supply of 3-5 watts over 5-7 years yields a huge mass reduction. Developing such technology for a LuSeN-type mission will allow for similar exploration of Mars and beyond.

Conclusions. A global lunar seismic network is required to safely establish a long-term Moon base. The Apollo seismic experiment highlights the dangers of shallow (tectonic) moonquakes and meteoroid impact events to any habitable structure. Shallow moonquakes need to be better characterized, and the effect of ground motion needs to be investigated [8], along with a statistical analysis of meteoroid impact locations. The Moon is a technology test bed for establishing such networks on Mars and beyond to facilitate safe exploration as well as advance our understanding of planetary interiors.

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USING SECONDARY OBJECTIVES TO GUIDE THE DEVELOPMENT OF LUNAR INDUSTRY. C. D. O'Dale, President, Senomix Software Inc. 64 Fairfax Dr., Suite 501, Halifax, Nova Scotia, Canada, B3S 1N5, info@senomix.com.

Introduction: This paper will discuss how secondary objectives imposed on scientific and commercial space resource projects may be used in place of legislation to regulate the development of lunar industry.

It may be expected that government legislation will be introduced to regulate the use of lunar resources and ensure their development continues at a responsible and measured pace; particularly for scarce, non-renewable resources such as deposits of volatiles at the lunar poles. However, in place of legislation to regulate the actions of lunar industry, inefficiencies may be imposed by government to force a measured pace of development dependant upon the completion of secondary goals.

Space projects of all sizes have historically been used to accomplish secondary objectives such as encouraging international goodwill and technical cooperation (through a division of project labour by nationality) or assisting commercial interests by reducing the risks for follow-on projects (by using unproven technologies on spacecraft to serve as a proof-of-concept). If space industries were forced to incorporate inefficiencies such as a mandatory human component in the process of staking claim to lunar and asteroidal resources, the pace at which resource claims and development proceeded would be limited by the ability of businesses to accomplish those objectives.

The inefficiency of involving human beings in a project which may be accomplished exclusively by more cost-effective robot technology would achieve the secondary objective of making human spaceflight a permanent part of lunar industry, while limiting the range of the first lunar businesses to a handful of claims and ensuring measured development of those first commercial territories. By linking the cost of human spaceflight directly to the profitability of lunar industry, such an inefficiency would also encourage the private sector to develop technologies which reduced the cost of human cis-lunar transportation; bringing a clear profit motive to the development of human spaceflight while not limiting the private sector in their implementation of accomplishing that objective.

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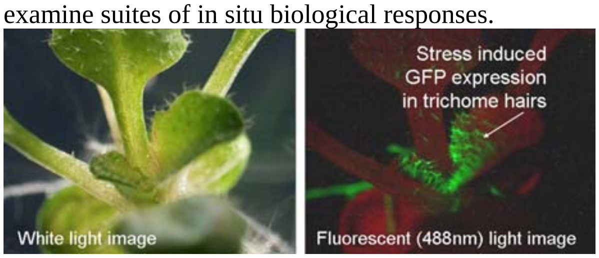
IN SITU BIOLOGICAL RESPONSE: SCALABLE ASSAY OF COMPLEX BIOLOGICAL PHENOMENA USING GENETICALLY ENGINEERED PLANTS. A-L. Paul[1], A. Schuerger[2] and R. J. Ferl[1], [1]University of Florida, Horticultural Sciences, Program in Plant Molecular and Cellular Biology, Gainesville, FL 32611. alp@ufl.edu , robferl@ufl.edu, [2]University of Florida, Plant Pathology, SLSL, Kennedy Space Center, FL 32899.

Science and Exploration Rationale:

As complex eukaryotic organisms, plants share basic metabolic and genetic processes with humans, yet their sessile nature requires that plants deal with their environment by adaptation in situ. Thus plants have evolved to deal with environmental change and stress by responding with changes in metabolism in order to meet the challenge, making them ideal reporters of the biological impact of their surroundings. Plants are therefore ideally suited for biological experimentation during near-term missions to the moon and other extraterrestrial environs [1]. Further, plants can make the journey within the stasis of the seed, under complete vacuum and extremely low temperatures. Given current and continued emphases in eukaryotic genomics, developmental and molecular biology, truly insightful experiments that address fundamental molecular questions about biological adaptation and responses to extreme extraterrestrial environments can be answered using plants.

A plant growth experiment is scalable over a wide range of variables that should be examined for biological impact. Such variables include atmospheric composition and pressure, transit and in situ radiation, gravity, and exposure to local resources. A plant growth payload is also scalable over a wide range of engineering and mission profile constraints. In a serriously constrained scenario, a few watts of power and a few cubic centimeters would allow examination of growth, development over several critical stages and gene expression in 10-20 plants - all within the course of a single lunar day. In a less constrained scenario, plants could be exposed to lunar regolith and a variety of mitigation technologies to enhance survivability and examine suites of in situ biological responses.



The plants to populate a Lunar or Mars lander experiment would be genetically engineered to be biological sensors (biosensors) of their environment. Plants engineered with Green Fluorescent Protein (GFP) reporter genes can be designed to respond to a variety of stimuli, they can be monitored telemetrically, and biological data can be collected in the form of digital images. Switching between normal lighting and that which facilitates the observation of GFP expression, will enable observation of both the general condition of the plants as well as monitoring of the development of fluorescent signals that cue a response to a specific feature of the environment [2-4].

In practice the plant growth payload would have a series of modules in which plants would be exposed to various aspects of the planetary environment as appropriate, with the size and number of modules being determined by the engineering trade space and mission profile [5]. Gravity would be an inherent component of the lander environment, as would be the incident radiation that penetrated the lander hull. Regolith collected by a robotic arm and returned to the growth space is a potential experimental variable that offers tremendous potential returns. Although there has been some experimentation with the effects of minute amounts of lunar regolith on plant growth in a neutral matrix [6], never has there been a test of its efficacy as a growth substrate and certainly not within the suite of conditions that exist in the in situ lunar environment.

A plant biology payload is both a fundamental test of biological survival outside the terrestrial environment as well as a technical and programmatic step in the development of advanced plant-based life support systems to support human exploration. Potential biotoxicity issues will be addressed directly. If plants can be grown safely in Lunar or Mars regolith, then the use of regolith within human rated habitats (whether as “soil” or simply as building material) becomes much more tenable and plants can then be used for the capture of in situ resources and the movement of those resources into the habitation environment [7].

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SCIENCE AND EXPLORATION OPPORTUNITIES THROUGH MOON MINERALOGY MAPPER.
Carle M. Pieters[1] and the M3 Team, [1]Department of Geological Sciences, Brown University, Providence, RI 02912 (Carle_Pieters@brown.edu).

Overview: The Moon Mineralogy Mapper (M3, pronounced m-cube) is a state-of-the-art high spectral resolution imaging spectrometer that will characterize and map the mineral composition of the Moon. The M3 instrument will be flown on Chandrayaan-1, the Indian Space Research Organization (ISRO) mission scheduled to be launched in late 2007. The Moon is a cornerstone to understanding early solar system processes, and M3 high-resolution compositional maps will dramatically improve our understanding about the early evolution of the terrestrial planets and will provide a high-resolution assessment of lunar resources.

M3 is one of several foreign instruments chosen by ISRO to be flown on Chandrayaan-1 to complement the existing strong ISRO payload package. After a detailed NASA peer-review process, M3 was selected for funding through NASA's Discovery Program as a Mission of Opportunity. M3 is under the overall oversight of PI Carle Pieters at Brown University. It is being built by a highly talented and committed team at JPL led by Tom Glavich as Project Manager and Rob Green as Instrument Scientist. Each member of the M3 Science Team is experienced and has a specific responsibility for data calibration and analysis. The rest of the Science Team includes: J. Boardman, B. Buratti, R. Clark, JW. Head, T. McCord, J. Mustard, C. Runyon, M. Staid, J. Sunshine, LA Taylor, and S. Tompkins.

The primary *science* goal of M3 is to characterize and map lunar surface mineralogy in the context of its geologic evolution. This translates into several sub-topics relating to understanding the highland crust, basaltic volcanism, and potential volatiles. The primary *exploration* goal is to assess and map lunar mineral resources at high spatial resolution to support planning for future, targeted missions. These goals translate directly into requirements for accurate measurement of diagnostic absorption features of rocks and minerals, with sufficient spectral resolution for deconvolution and at high spatial resolution within spatial context. These requirements are met by M3's design: visible to near-infrared imaging spectrometer with high signal to noise, and excellent spatial and spectral uniformity.

M3 spectral requirements are from 0.7 to 3.0 µm (optional to 0.43 µm is the baseline). Measurement of lunar targets are obtained for 640 cross track spatial elements and 261 spectral elements. This translates to 70 m/pixel spatial resolution and 10 nm spectral resolution (continuous) from a nominal 100 km polar orbit for Chandrayaan-1. Spectra of lunar soils and minerals sampled to the full resolution of M3 are shown in Figure 1. The M3 FOV is 40 km in order to allow contiguous orbit-to-orbit measurements at the equator that will minimize lighting condition variations.

Over the two-year lifetime of the mission, there are four periods of optimal lighting conditions for spectroscopic measurements (two 2-month periods per year). One period will be devoted to global assessment at reduced resolution (320 spatial elements, 87 spectral) and the other three will be devoted to obtaining full resolution data for prioritized targets (10-50% of the surface). The nominal mission relies on India's new Bangalore DSN facility for data downlink. This implies that data for only 6 of 12 orbits/day will be transmitted when the Moon is in sight of Bangalore DSN. The nominal measurement timeline and data collection sequence for M3 is shown in Figure 2.

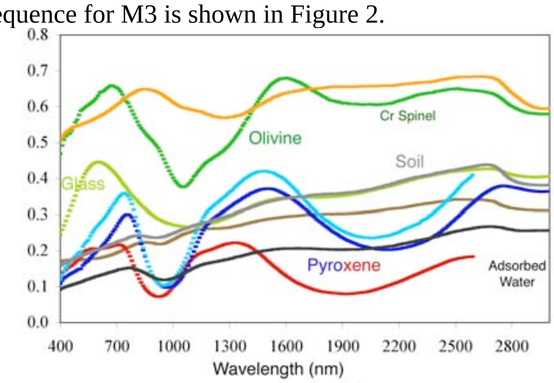


Figure 1. Example reflectance spectra of lunar minerals and soils sampled to M3 full resolution. [The weak feature near 2900 nm is due to trace amounts of terrestrial water remaining on the samples in a purged environment.]

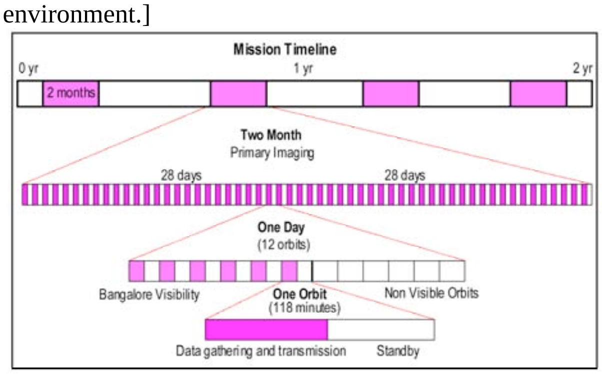


Figure 2. M3 data acquisition periods during a nominal Chandrayaan-1 mission timeline.

Mission Status: M3 has had a Preliminary Design Review (PDR) and is scheduled for Critical Design Review (CDR) in early 2006. International agreements are proceeding in parallel with instrument design and implementation.

EARTH MOVING INDUSTRY - LABORATORY AND NUMERICAL MODELING TOOLS APPLIED TO LUNAR ENVIRONMENTS

E. A. Reiners[1] and P. T. Corcoran[1],
[1] Caterpillar Inc., Technical Center, P.O. Box 1875, Peoria, Ill., 61656-1875 Reiners_Eric_A@cat.com, corcoran_paul_t@cat.com

Introduction: Long-term Moon and Mars missions will require planetary infrastructure for *In-Situ* Resource Utilization (ISRU) and living facilities on a scale previously unknown in planetary exploration. The construction of these facilities plus ISRU tasks will require equipment capable of excavating, transporting and accurately emplacing relatively large masses of Regolith. These tasks need to be accomplished without the traditional terrestrial techniques that utilize a suite of specialized heavy equipment vehicles where each performs one or two tasks. The planetary construction equipment will need to be light, compact, power efficient, modular and capable of performing several varied tasks in support of facility construction and ISRU and capable of accomplishing these under autonomous and/or manned control.

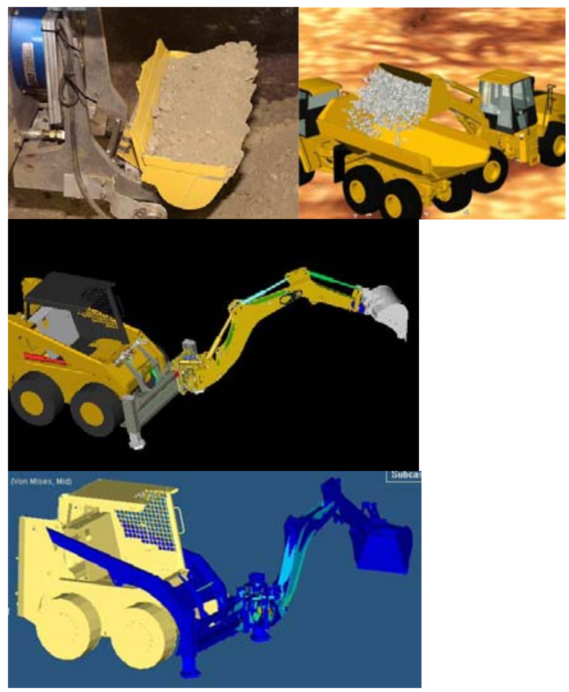
Current state-of-the-art laboratory and numerical modeling tools used in the development of earth based regolith moving equipment should be leveraged to expedite the concept and development of Lunar/Mars regolith handling equipment. Current state-of-the-art tools include:

- Regolith Scale Modeling Laboratories
- Numerical Regolith Modeling
- Numerical Machine Modeling and Regolith Integration
- Numerical Site Modeling of Systems of Machines

The next steps in leveraging these tools for Lunar Regolith Handling Machines and Systems, include:

- Developing a thorough understanding of the physical and mechanical properties of the material
- Incorporating this understanding as inputs to the above mentioned tools and modifying the tools as necessary to represent the Lunar/Mars environment
- Capturing the desired tasks and requirements of surface machines.
- Using the above tools and requirements to develop and evaluate machine concepts including end-effectors, enhanced traction or anchoring technologies. Site simulation and evaluating systems of machines will be a necessary part of the concepting task.

The vision of the final machine concepts are light, modular "host" machines providing propulsion and power for a wide variety of work tools to meet mission tasks and requirements.



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ADVANCED PLANETARY DRILL TECHNOLOGY AND APPLICATIONS TO FUTURE SPACE MISSIONS.
J.W. Reiter[1], J.L. Guerrero[1], D. Wu[1], G.Y. Wang[1], [1]Swales Aerospace (404 N. Halstead Ave, Pasadena, CA 91105, jreiter@swales.com).

Introduction: Planetary drilling has great potential for become a vital, enabling technology in the context of future human and robotic exploration of the Solar System. From the perspective of a "system-of-systems" concept for mission architectures and exploration approaches, the ability to drill into extra-terrestrial planetary bodies and recover samples for analysis and/or utilization can provide vital references, resources, and opportunities for mission enrichment. Likewise, the technology for supporting and planning such missions presents a feed-forward advantage for a human presence in such environments. We will describe relevant challenges to mission planning and development pertaining to operations within hostile planetary environments. Future space missions for drilling in the mid-to-deep subsurface face issues unfamiliar to terrestrial analogues, including limited power, very low or very high pressures, and widely varying thermal environments. We will discuss the means and approaches for establishing drilling operations, managing drilling sites, and mitigating environmental effects. Specific needs for human exploration relate to the ability for remote missions to scout potential locations for habitability and/or resource recovery. Early robotic phases will leverage system-of-systems collaborations among humans and machines on and above the surface of planetary bodies. Such "precursor missions" will be charged with the task of mapping subsurface geology, understanding soil/rock particle distributions, obtaining geologic history, and determining local resource profiles. An example of the need for this kind of information is given to good effect by one of the lessons learned by NASA's Apollo program: the effects of lunar dust on humans, mechanisms, and mission expectations were far greater than initially expected, and are still being critically considered. Future missions to Solar System bodies, including the Moon and Mars, will need to have advance information about local geologic effects, especially below the visible surface. In these hostile environments, valuable resources (e.g., water and other volatiles) will probably be hidden in substrata. Prospecting, mapping, excavating, and recovering these resources will remain a central need for NASA's exploration efforts for the foreseeable future. Swales Aerospace has a proven history in the development of planetary drilling technology and research. We will show some results of a successful field campaign, during which our prototype planetary drill reached a depth of 10 meters with an average power consumption of only 100 Watts. We will discuss a recent paper study for Very Deep (~1000 m) drilling in the Martian environment and our perspective on the development of mission profiles for planetary drilling. We will suggest architectures for future drilling missions, potential configurations for deployed planetary drills, and provide comments on launch/flight/landing capabilities, including relevant engineering challenges such as mission time, power, mass, and communications.

The numerical modeling of sensitivity of the Lunar Exploration Neutron Detector for the NASA Lunar Reconnaissance Orbiter. A. B. Sanin[1] and R. D. Starr[2] with LEND Instrument Team, [1]Space Research Institute (IKI), 84/32 Profsoyuznaya str, 117997, Moscow, Russia, [2]Department of Physics, The Catholic University of America, Washington, DC 20064

Introduction: Here we would like to present results of numerical modeling of sensitivity to hydrogen of the Russian Lunar Exploration Neutron Detector (LEND) instrument during its operation around the Moon onboard the NASA Lunar Reconnaissance Orbiter (LRO). The main goal of this modeling is to find an optimal design of the instrument in condition of strong mass limitation and in the same time to get as much sensitivity to hydrogen as possible.

Lunar Exploration Neutron Detector overview: Lunar Exploration Neutron Detector (LEND) is designed to fulfill several LRO objectives. The main goals of LEND experiment are to develop maps of water ice column density on lunar polar regions with spatial resolution from 5 - 20 km and to determine hydrogen content of subsurface at polar regions with spatial resolution from half width at half maximum (HWHM) = 5 km and with variation sensitivity from 100 weight parts per million (ppm).

LEND contains eight ^{3}He proportional counters for measuring thermal and epithermal neutrons and one detector based on a stylbene crystal surrounded by plastic anticoincidence shield for fast neutrons.

^{3}He detectors must be collimated to perform measurements with high spatial resolution of neutron flux from Moon surface. Spatial resolution of uncollimated sensors is about the visible area of Moon surface. Our estimated total mass of the LEND shows that an instrument with this design will fully satisfy all objectives if its mass is about 23 kg. Mass estimations of electronic components, detectors and chassis gives about 10 kg and leaves 13 kg for collimators. These mass were fixed on early stage of project and next efforts are directed to find an optimal composition, structure and shape of collimator.

Numerical modeling of the LEND sensitivity: To optimize the collimated sensors we use the MCNPX code produced by Los Alamos National Laboratory. This is Monte Carlo N-particle transport code for multiparticle and high energy applications. The modeling of neutrons spectral and angular distribution on the LRO orbit around Moon was performed and used for modeling of counting rate in the collimated sensor. The collimator structure and the points to be optimized are shown on the Figure 1. On Figure 2 we present numerical modeling results of the several versions of collimator geometry. We select the case of collimator with 30 cm length, 4.5 cm open side radius and 4.412 kg mass. LEND contains four such collimators. About 26% of collimator mass can be deleted from intercollimator space. This is possible because collimators shield each other from neutron fluxes that come at high angles to detector axes.

In Table 1 we present estimated sensitivity of LEND for hydrogen detection at spots with different sizes placed at lunar polar regions at 3σ significance level. This sensitivity allows LEND to detect water ice deposits inside the main cold traps around poles identified on the Moon [2].

Table 1.

Size of spot / Distance from pole	5 km	6 km	10 km
0	**82.5**	**56.0**	**28.4**
30 km (89°)	**278.8**	**164.2**	**62.8**
90 km (87°)	**526.2**	**298.3**	**110.7**
150 km (85°)	**726.5**	**398.6**	**144.6**

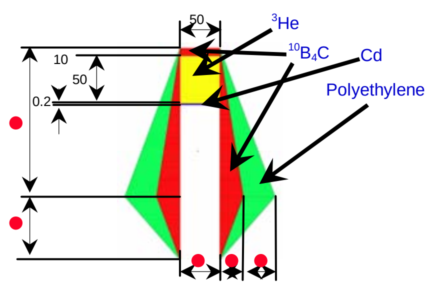


Figure 1. Structure of the one collimated sensor. The dimensions to be optimized are shown by red circles.

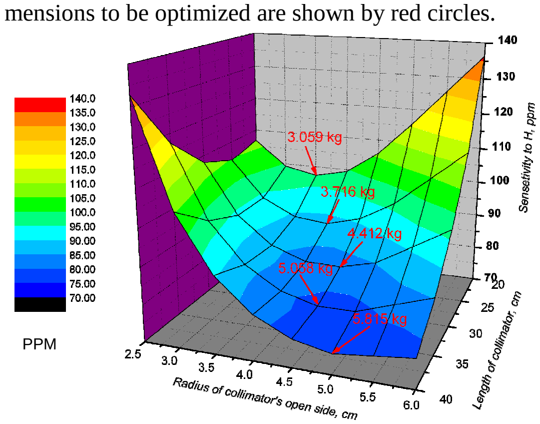


Figure 2. LEND sensitivity to hydrogen depend on the collimator length and radius of its open side. Estimation of collimator's total mass are shown for a few cases.

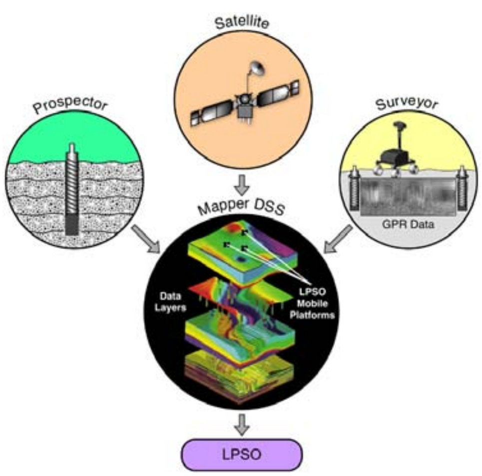
References: [1] Mitrofanov I.G. et al. this issue, (2005). [2] Litvak et al., this issue (2005).

The CRUX-Mapper/DSS: A Real-Time Decision Support System for In-Situ Resource Utilization.
J. D. Schlagel[1] and H. M. Jensen[1], [1] Remote Sensing/GIS Center Army Cold Regions Research and Engineering Laboratory. Hanover, NH

Introduction: The success of future lunar missions will depend on the ability to rapidly assess and identify optimal sites to conduct lunar surface operations related to in-situ resource utilization (ISRU), construction, environmental management, and surface mobility. Successful operations will require a good knowledge of surface topography, geotechnical properties (e.g., grain size, mineralogy, bulk density, thermal and mechanical properties) and whether water is present.

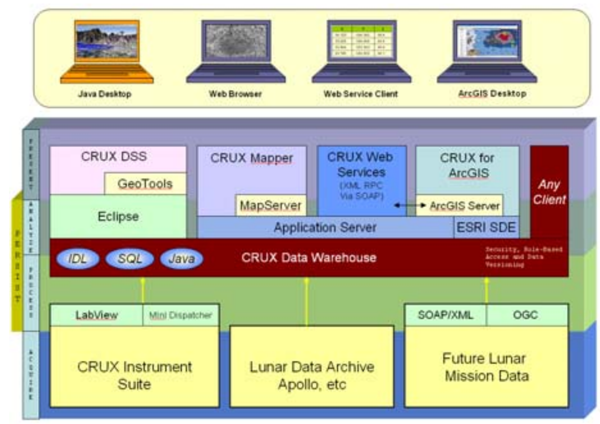
The Contstruction Resource Utilization Explorer (CRUX) is an integrated, but modular, suite of instruments and related software, consisting of an instrumented drill (Prospector), surface geophysical and optical mobile sensors (Surveyor), linked with a mapping and decision support system (CRUX-Mapper/DSS), as shown in Figure 1. Using CRUX satellite data is used to identify a target of interest to coarse resolution. The Surveyor's geophysical instruments will map shallow subsurface regions to help locate optimal drilling sites. The Prospector's drill will carry instruments down-hole to measure site-specific regolith geotechnical properties and detect water.

Figure 1. The CRUX System



The CRUX-Mapper/DSS (Figure 2) represents a service-oriented approach to the acquisition, management, analysis and dissemination of real-time geospatial data and anlysis collected during CRUX missions. Using the Mapper/DSS, CRUX data and mission telemetry will be acquired and managed as eXtensible Markup Language (XML) documents over a scalable web service bus. Web Services will be used not only to acquire but to process and disemenite data at all levels of processing from raw telemetry to reduced data streams to model output .

Figure 2. Architecture of The CRUX Mapper/DSS



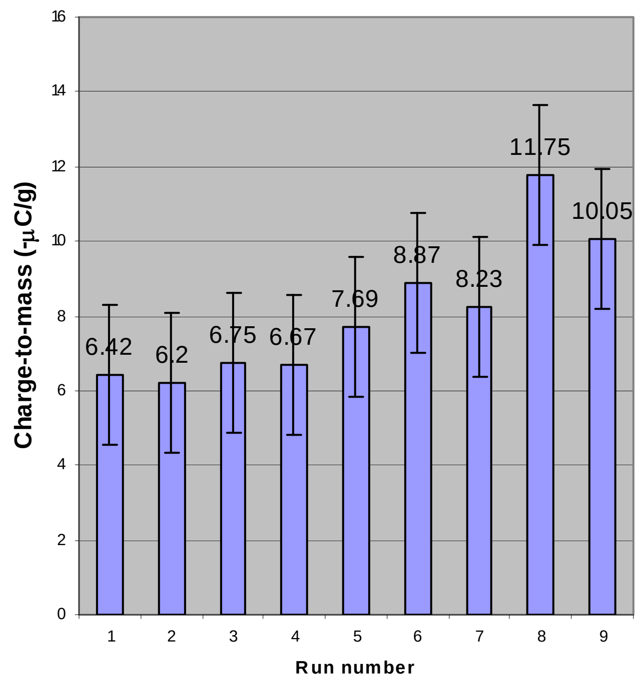
Principal technical components of the CRUX Mapper/DSS include Oracle database with spatial and temporal data elements for data persistence, management, and replication, IDL for server side data reduction and analysis, the Eclipse Java development platform for alignment and integration with the ongoing SAP/Maestro software development effort, commercial and open source geospatial components including GIS from ESRI, geotools and mapserver.

Principal data sources beyond the CRUX instrumentation suite will include archival Apollo and Clementine mission science data processed for inclusion in new science programs, and remotely sensed data from future missions. This data will be available via web services and other protocols for incusion in real-time 3-D, 4-D modeling of CRUX data .

The final outcome of the CRUX-Mapper/DSS will be a series of science-based engineering guidelines and data interpretation protocols implemented in software. These will yield predictable outcomes in the form of go-no-go decision support tools for future lunar missions.

ELECTROSTATIC PROPERTIES OF MARS/LUNAR DUST SIMULANTS AND THEIR EFFECTS ON THE PERFORMANCE OF DUST MITIGATION DEVICES. R. Sharma, P.K. Srirama, C.E. Johnson, M.K. Mazumder, K. Pruessner, and D.W. Clark, Department of Applied Science, University of Arkansas at Little Rock, 2801 S. University Avenue, Little Rock, AR 72204, Tel: (501) 569 8007, mkmazumder@ualr.edu.

Introduction: During the period of three months March-May 2005, NASA research laboratories including JSC, JPL, NASA Ames, KSC and GRL, conducted two workshops, one in California and the other in Colorado, to discuss (1) the biological effects of Lunar dusts and environmental protection against dusts in robotic and human missions to the Moon and to Mars and (2) to develop appropriate dust mitigation technologies. Electrostatic properties of dust as a function of particle size and shape were considered a major concern on Mars and Lunar missions with respect to both the dust mitigation and biological effects. We present here methods of (1) particle size classification, (2) simultaneous measurements of particle size and electrostatic charge distributions, and (3) performance evaluation of dust removal devices as function of size and charge. Experimental data on (1) particle size classification, (2) triboelectric charging of simulant dust collisions between (a) particle – particle, (b) particle – Teflon®, and (c) particle – stainless steel, and (3) charge neutralization are presented. Development of experimental techniques to characterize electrostatic charging and dust removal processes in simulated lunar and Martian conditions are presented. Development of dust monitoring and dust removal devices for in-situ applications to Lunar and Mars missions are briefly reported.



Charge-to-mass ratio (Q/m) of new Mars stimulant dust (JSC-1). The dust was tribocharged for 30 minutes in a glass tumbler.

POTENTIAL SCIENCE AND EXPLORATION LINKAGES BETWEEN THE MOON AND MARS.

C.K. Shearer, Institute of Meteoritics, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, New Mexico 87131 (cshearer@unm.edu).

Introduction: Within the new direction of solar system exploration proposed by the President of the United States, potential science and exploration linkages between the Moon and Mars have become increasingly important. Are there important technological and scientific concepts that could be developed on the Moon that will provide valuable insights into both the origin and evolution of the terrestrial planets and be feed-forward to the scientific exploration of the much more distant Mars? Within the oversight of MEPAG, the Moon→Mars Science Linkage Science Steering Group identified important lunar scientific and technology goals and evaluated them with regards to how they could provide insights for the exploration of Mars [1]. The steering group identified six important lunar science and technology themes.

Early Planetary Evolution and Structure: The Moon has been and will continue to be the scientific foundation for our understanding of the early evolution of the terrestrial planets. It provides a valuable and nearly complete end-member model for a style of planetary differentiation and early planetary magmatism. The detailed geologic record of these early events has long since vanished from the Earth and has been at least partially erased from Mars. Four Moon-Mars topics were examined that fit within this theme:

- *Composition & Structure of Planetary Interiors*
- *Early Planetary Differentiation*
- *Planetary Thermal & Magmatic Evolution*
- *Planetary Asymmetry*

Evolution of Planetary Surface: Some surface modification processes will be very similar for the Moon and Mars, and others will differ due to the presence of fluid erosion and chemical weathering on Mars. Three topics were examined that fit within this theme:

- *Impactor Flux versus Time*
- *Interpreting Geologic Surface Environments*
- *Structure & Composition of Regoliths*

Record of Volatile Evolution and Behavior: This is perhaps the most important overall theme for the major stated goals for the Mars Exploration Program of life, water, and climate. As Mars and the Moon are at nearly opposite ends of the volatile spectrum for rocky planets, most of the volatile science studies to be conducted on Mars are not possible on the Moon. However, there are several special cases where the study of lunar volatiles may be relevant to Mars:

- *Energetic Particle History*
- *Origin & History of Endogenic Volatiles*
- *Origin & History of Exogenous Volatiles*

Human Resource Issues: Long-term human outposts on Mars and the Moon can benefit from applying local resources to outpost support in areas that include construction of facilities to providing reservoirs of important consumables (water, oxygen, nitrogen, etc.) from local resources. The Moon is viewed as a place where the basic principles can be tested for the first time. Three topics were examined in this theme:

- *Water as a Resource*
- *In-situ Fuel Sources*
- *Exploration & Processing of Planetary Materials*

Technological Demonstrations: Because of its proximity to Earth, the Moon provides a functional technological testbed for developing technical capabilities for the scientific exploration the Mars by robots and by humans. Although most of these probably could be done first on Mars, the technical feasibility of these measurements can be significantly advanced and associated risks mitigated on the basis of a lunar testbed experience. Also, the testbed experience should further improve performance and confirm capabilities. Seven topics were explored:

- *Communication & Ranging Systems*
- *ISRU Technology Demonstrations*
- *Drilling Technologies*
- *Seismic Net Technologies*
- *Assess Bio-Organic Contamination*
- *Sample Selection-Characterization Technologies & Strategies*
- *Sample Return Technologies*

Astrobiology: Astrobiology is the quest to understand how habitable planets form and how inhabited worlds evolve, as well as the prospects for life beyond the Earth. This theme tends to overlap with many of the above themes and topics and can be divided into two categories: historical and technological.

Conclusion: Although the Moon and Mars represent significantly different planetary environments and pose distinctly different problem for their exploration, the steering group identified a rich array of scientific and applied science linkages. These linkages range from a fundamental understanding of planetary pathways of evolution to technological demonstrations required for robotic and human exploration of the solar system. Setting priorities among linked themes and topics is highly dependent upon evolving goals for both the Moon and Mars Exploration Programs.

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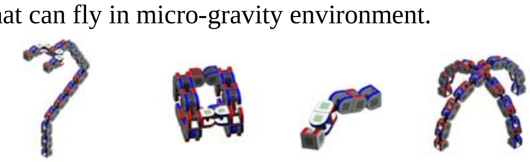
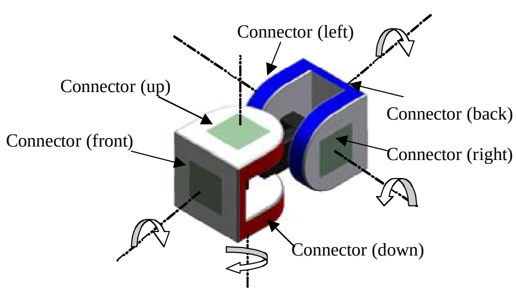
SUPERBOTS: MODULAR, MULTIFUNCTIONAL, RECONFIGURABLE ROBOTIC SYSTEM FOR SPACE EXPLORATION.

W.-M. Shen[1] J. Bogdanowicz[2], W. Chun[3], M. Yim[4], P.M. Will[1], M. Sims[5], S. Colombano[5], D. Kortenkamp[6], S. Vanderzyl[7], E. Baumgartner[8], J. Taylor[9]. [1]USC/ISI (4676 Admiralty Way, MDR, CA, 90292, shen@isi.edu), [2]Raytheon, [3]Lockheed Martin, [4]UPenn, [5]NASA ARC, [6]Metrica, [7]ASI, [8]JPL, [9]U.Hawaii.

Introduction: Robotic systems are essential for space and lunar exploration. They perform tasks that range from inspection, maintenance, and assembly in space, to scientific exploration, transportation, habitat construction, resource utilization, and astronaut assistant on planetary surface. However, the traditional approach of building special robots for each of a large variety of tasks is not practical as it requires many specialized robots that are expensive and difficult to deploy from earth. This paper proposes a new *Superbot* robotic system that uses modularity and self-reconfiguration as an effective means to achieve low cost, multifunction, and adaptive capabilities. This approach has been partially realized under the support of NASA's H&RT program. This paper describes the unique features and experimental results of the Superbot modules and systems, and highlights a set of space applications using Superbots. The details of applications are described in the companion abstracts.

Superbot System Features: The Superbot system consists of a set of Lego-like but autonomous robotic modules that can *self*-reconfigure into different systems for different tasks. Examples of configurable systems include rolling tracks or wheels (for efficient travel), spiders or centipedes (for climbing), snakes (for burrowing in ground), long arms (for inspection and repair in space), and devices that can fly in micro-gravity environment.





Each Superbot module is a complete robotic system and has a power supply, micro-controllers, sensors, communication, three degrees of freedom, and six connecting faces (front, back, left, right, up and down) to dynamically connect to other modules. This design combines the advantages of many existing reconfigurable robots such as CONRO, PolyBot, MTRAN, and ATRON, and allows flexible bending, docking, and continuous rotation. With these features, any single Superbot module is a complete robot itself and can move forward, back, left, right, flip-over, and rotate as a wheel. Modules can communication with each other for totally distributed control and can support arbitrary module reshuffling during their operation. They have both internal and external sensors for monitoring selfstatus and environmental parameters. They can form arbitrary configurations (graphs) and can control these configurations for different functionality such as locomotion, manipulation, and self-repair. With a standard interface for docking, Superbot modules can connect to any specialized instrument, tool, or device and use them as an integrated part of the system.

Experimental Results: Under the NASA's H&RT program, the team has built prototypes of Superbot modules, tested behaviors of a single module, collaborations of modules, and simulated many challenging system behaviors. A single Superbot module has been demonstrated to move forward, backward, turn left and right, and flip-over from upside-down, and can run 250 meters with 33% of battery capacity and an average speed of 6.9cm/s. A two-module Superbot robot has been shown to move like a caterpillar, a sidewinding snake, and can stand up on various faces. A four module Superbot has been shown to roll like a track. In simulation, Superbot robots with multiple modules can form configurations such as chains, trees, legged walkers, rolling tracks, snakes, centipedes, balls, and long-arms. A 6-module rolling track can move 100cm/s on flat terrain and another configuration can climb slopes up to 50 degree. All control algorithms are distributed and support arbitrary dynamic reconfiguration. Our next step is to demonstrate the reconfiguration of the system.

Applications for Space Exploration: Various application scenarios have been developed to utilize Superbot's novel capability, including [1] Multi-Use Lunar Explorer (MULE), [2] a Habitat Maintenance and Operations System (HOMS), [3] a cost-effective robotic method to detect H2O or seismic features, and [4] a set of flying maneuvers and mini-RMS for inspection and maintenance on and near CEV or Space Station.

References: [1] Lentz et al., this volume, [2] Taylor et al, this volume, [3] Lawrence et al, this volume, and [4] Kortenkamp et al, this volume.

TOWARD A SUITE OF STANDARD LUNAR REGOLITH SIMULANTS FOR NASA'S LUNAR MISSIONS: RECOMMENDATIONS OF THE 2005 WORKSHOP ON LUNAR REGOLITH SIMULANT MATERIALS

L. Sibille[1], P. Carpenter[1], and R. A. Schlagheck[2].
[1]BAE Systems Analytical and Ordnance Solutions, NASA Marshall Space Flight Center XD42, Huntsville, AL Laurent.Sibille@msfc.nasa.gov and Paul.Carpenter@msfc.nasa.gov
[2]NASA Marshall Space Flight Center XD41, Huntsville, AL 35812

Introduction: As NASA turns its exploration ambitions towards the Moon once again, the research and development of new technologies for lunar operations face the challenge of meeting the milestones of a fast-pace schedule, reminiscent of the 1960's Apollo program. While the lunar samples returned by the Apollo and Luna missions have revealed much about the Moon, these priceless materials exist in too scarce quantities to be used for technology development and testing. The need for mineral materials chosen to simulate the characteristics of lunar regoliths is a pressing issue that is being addressed today through the collaboration of scientists, engineers and NASA program managers. The issue of reproducing the properties of lunar regolith for research and technology development purposes was addressed by the recently held Workshop on Lunar Regolith Simulant Materials at Marshall Space Flight Center. The conclusions from the workshop and considerations concerning the feasibility (both technical and programmatic) of producing such materials will be presented here.

Present Status of Lunar Simulant Materials: No standard reference lunar simulant materials currently exist in the U.S.A.. NASA defined and provided such materials in the past for the development of the Apollo Landing Module and Lunar Rover Vehicle. While no Apollo lunar simulants remain today, the more recent efforts led to the development and distribution of materials such as MLS-1, a titanium-rich basalt from Minnesota and JSC-1 [1], a glass-rich basaltic ash from the volcanic fields of the San Francisco mountains of Arizona. Both of these simulant materials were successful in the sense that they provided known source materials for researchers but were not standardized and were only adequate for certain applications. The lack of funding and the waning interest from NASA in the 1990's resulted in disappearing stocks and the resurgence of a variety of 'home-made' lunar simulants and independent commercial materials. In parallel to NASA-funded simulants, the Japanese space agency JAXA, has developed lunar simulants such as FJS-1, and MKS-1 in the last ten years [2] and canadian anorthosite materials are being evaluated. These materials have been characterized extensively in terms of bulk chemical composition, mineralogy, geotechnical properties and are used in Japan but are only available in modest quantities. In the wake of the 2005 Workshop on Lunar Regolith Simulants, a renewed effort is underway to make JSC1-like materials (labeled JSC1a) available.

Recommendations and requirements for Lunar Regolith Simulants: The participation of many experts in lunar science, materials development, space resource utilization, dust toxicity, and soil mechanics enabled the workshop to issue specific recommendations to NASA. The expert group recommends the development of dictinct standard *root* lunar simulants representing low-Ti mare basalts and high-Ca highland anorthosites to address the basic rock types found on the Moon. These materials would serve as end-members to elaborate *derivative* simulants through mixing and addition of specific components. Additions of minerals such as ilmenites, glass components mimicking agglutinates and concentrations of nanophase iron are recommended to achieve higher fidelity of lunar materials simulation. Experimental development of a dust fraction (< 20 μm) mainly comprised of glass and mineral fragments is also strongly recommended since this fraction of the lunar regolith can represent up to 30% by mass [3]. One major obstacle to this task is the strong dependence of several regolith properties on the lunar environment itself. Surface properties such as adsorption, adhesion, chemical reactivity, and electrocharging are defined by the absence of oxidation, the ambient vacuum and the illumination by the full solar light spectrum. In fact, one should consider carefully the problems raised by the accumulation of requirements such as mineral chemistry, crystallinity, glass content, aspect ratios and surface properties that may render the production of simulants unfeasible technically and economically. In the end, the choice of standard reference materials for lunar simulants must be made now to support NASA's technology development for the early Robotic Exploration Program missions and extended duration missions to the lunar surface.

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RELIABILITY AND LUNAR BASE CONCEPTS. Jackelynne Silva jackysil@eden.rutgers.edu; Haym Benaroya benaroya@rci.rutgers.edu; Department of Mechanical & Aerospace Engineering, Center for Structures in Extreme Environments, Rutgers University, 98 Brett Road, Piscataway, NJ 08854

Introduction: Why do we want to go to space? Specifically, why go the Moon and have a settlement there? The following are the most driven reasons: Lunar science and astronomy, as a stimulus to space technology and as a test bed for the technologies required to place humans on Mars and beyond, the utilization of lunar resources, establishment of a US presence, stimulate the interest of young Americans in science and engineering, and as the beginning of a long-range program to ensure the survival of the species.

Human safety and the minimization of risk to an "acceptable" level is usually the top consideration in any project. It is clear that to go to the Moon represents a challenge, mostly because it is a new environment and the many unknowns provide the design engineers many uncertainties. In order to minimize possible risks, structural redundancy must be used, and when everything else fails, an easy escape for inhabitants must be ready. However, what is considered to be "acceptable" for a lunar construction and under what conditions? We will encounter some problems; but, can we afford to fail?

Reliability is a specialized term for the analysis and design of systems where certain aspects of the environment and system have associated uncertainties [1]. This idea lets us see how important it is to know small details at the time of doing any construction, which can be ignored in less risky environments; such small details can become the Achilles heel that can put lives and facilities at great risk. Uncertainties imply the need to use statistical and probabilistic tools in the analysis and design process.

Using the concepts from earthquake engineering, for example, we can study how to approach lunar base design studies. Of course, probabilistic approaches are only as precise as the assumptions and data allow. However, in earthquake modeling, a probabilistic analysis can tell us approximately the time, area, and at what magnitude the event may happen, and based on these estimates our designs are optimized. We can, hopefully, minimize the danger.

Of course, even the uncertainties inherent in earthquake engineering pale by comparison to reliability of structures for the Moon. This is a little-known area, but there is enough information to begin to consider, study and investigate the reliability of such structures.

We want to address points that will verify that a certain construction is dependable and offers "trust" for people in charge of the construction, investors, astronauts, inhabitants, tourists, and the public in general living on the Moon and Earth.

What are we talking about? What is reliability? How can we minimize risks? For a better understanding, a scheme is proposed for the main points that should be taken into account when we talk about reliability.

We need to have a design process. A diagram that shows what needs to be considered will be explained. Prototyping, conceptualization and evaluation are the steps to follow. We will explain in detail how concurrency is used here and the relation between reliability and the total life cycle.

A design philosophy is proposed within the scheme of reliability concepts, which demand higher factors of safety compared to those taken on Earth [1]. This design establishes relationships between, and shows the importance of having a good understanding of, redundancy, parallelism, and logistics.

The primary contributions of this work is to consider the reliability of a structure proposed by Ruess et al. [2]. Related to this is the examination of how various classes of structures are amenable to a reliability analysis, and whether one has an overall advantage.

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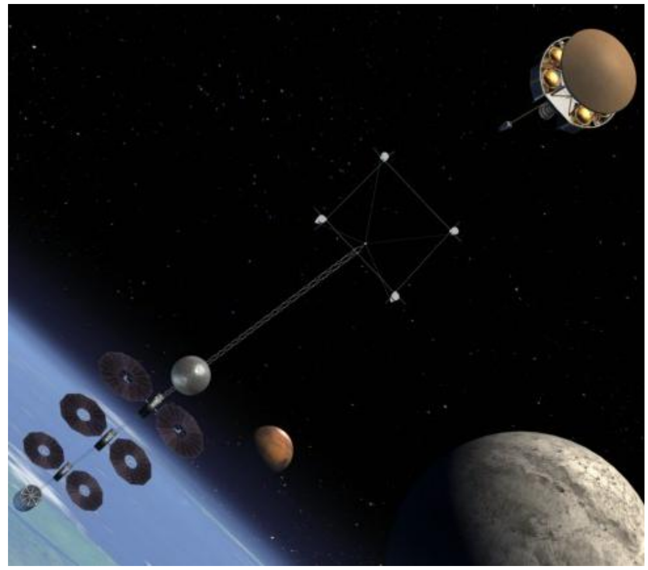
CISLUNAR TRANSPORATION ARCHITECTURE INFLUENCES ON ISRU AND SCIENCE. K. F. Sorensen[1] and J. A. Bonometti[2], [1]NASA (NASA/MSFC, MS: NP40, MSFC, AL 35812; kirk.f.sorensen@nasa.gov), [2]NASA (NASA/MSFC, MS: NP40, MSFC, AL 35812; joseph.a.bonometti@nasa.gov).

Introduction: Future utilization of lunar resources will depend greatly on the space transportation costs, as well as flexibility, associated with their use. Cislunar transportation architectures using only rocket-based propulsion have fundamental limitations in performance and cost. They require the propellant resource to be fully processed into rocket fuel at the raw-material collection site and then consume a large percentage of the commodity in its own transportation. Tether based transportation architectures provide a unique and viable way of overcoming these limitations. The use of momentum-exchange tethers promises to dramatically reduce these transportation costs by extracting orbital angular momentum directly from planetary bodies. Around the Earth, rotating momentum-exchange tethers could throw payloads from low-energy to trans-lunar trajectories and then utilize electrodynamic tether propulsion to restore orbital energy and momentum. At the Moon, spinning tether slings on the lunar surface could throw lunar materials to lunar orbit, L1, or even on a trans-Earth injection trajectory. The lunar slings could also be used to build up materials at L1 for the construction of an anchored lunar tether, which could then be used for two-way transportation of personnel and cargo to the lunar surface. The resource being transferred has the additional advantage that it can be any stage of the manufacturing process when it is transported (i.e., lunar regolith to high-purity liquid oxygen). This presentation will discuss the physics, engineering, operations, and constraints of each tether option and how they deploy sequentially to develop truly sustainable and low-cost cislunar transporation architectures in the near future.



SIMULATING THE MOON'S GRAVITY ON EARTH USING MAGNETIC LEVITATION *

Donald Strayer, Yuanming Liu, Charles Hays, Richard Kidd, and Ulf E. Israelsson Jet Propulsion Laboratory, California Institute of Technology Pasadena, California, U.S.A. 91109-8099

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We will present a description of a facility that is currently under construction at JPL to simulate the Moon's gravity. It is a laboratory-based variable-gravity testbed that will be used to study fluid and biological systems in simulated gravity levels other than Earth's gravity, such as those on Mars (0.39g), the Moon (0.16g), Europa (~g/7), or in space (0g). This facility represents an example of using Physics and Quantum Technology to achieve technological advantage to support NASA`s new vision for human and robotic exploration.

The centerpiece of the facility is a superconducting gradient magnet with a rather large room-temperature bore. The magnet generates magnetic body forces acting on a body or fluid to counter or enhance Earth's gravity, achieving simulated gravity levels tunable from 0 g to several g.

The magnet will be constructed using Nb_3Sn for the inner coils and NbTi for the outer coils. The magnet will be immersed in 2.2K liquid helium, and will be operated in the persistent mode; liquid helium top-ups occur once each 10 days without interrupting the magnet's function. Because of this unique operation mode of superconducting magnets, one can operate the magnet for a long period of time (months) without recharging, making long-duration experiments possible without consuming enormous amounts of electricity and liquid helium. The magnet will be capable of producing more than 14.5 Tesla^2/cm in the product of field and field gradient, generating a magnetic force strong enough to levitate (cancel Earth's gravity force upon) water and most biological materials. The large room-temperature bore (6.6 cm, or 2.6 inches) permits us to study sizable fluid samples of common fluids, and to observe biological systems at or near room temperature at many gravity levels, and to observe cryogenic fluids at reduced temperature in a cryostat insert.

With this versatile facility, we shall focus on two areas of research in fluid systems. First, we shall study heat and mass transfer as a function of gravity in Rayleigh-Bénard thermal convection; Marangoni convection; gas-liquid two-phase systems; binary fluids; and fluids in confined media such as microchannels, aerogels, and granular materials (such as soil and sand). These studies will provide us understanding on how these fundamental physical phenomena are affected by the gravity levels and will lead us to understand the ways that fluid technologies will behave on other planets.

Second, based on the knowledge gained, we shall test and optimize the designs of flight thermal fluid devices that are to be used in the life-support fluid systems and resource utilization systems for human and robotic explorations and colonization of other planets and moons. By operating scale models of fluid devices in our levitation magnet, we shall study the performance of the following devices at reduced gravity levels: heat exchangers, liquefiers, refrigerators, heat pumps, evaporators, sublimators, and two-phase flow loops. Optimization of these devices for the intended gravity environment will help us to achieve best performance, thus reducing the devices' mass and power consumption, very precious commodities for space exploration.

Other than fluid systems, the facility will be open to investigators to study how biological systems behave under the gravity of other planets and the Moon. The ability to easily alter effective gravity levels will facilitate looking for thresholds on effects of reduced gravity.

The facility is expected to be operational in about a year, fully equipped with electronic instrumentation, visualization optics, and data acquisition systems. We are also considering establishing support systems for small animals to be tested at reduced gravity levels.

IMPACT OF ELECTRICALLY-CHARGED DUST ON LUNAR EXPLORATION. T.J. Stubbs, R.R. Vondrak and W.M. Farrell, NASA/GSFC, Greenbelt, MD 20771, USA, Timothy.J.Stubbs.1@gsfc.nasa.gov.

Introduction: All astronauts who walked on the Moon reported difficulties with lunar dust. Eugene Cernan, Apollo 17, stated that *"one of the most aggravating, restricting facets of lunar surface exploration is the dust and its adherence to everything no matter what kind of material, whether it be skin, suit material, metal, no matter what it be and it's restrictive friction-like action to everything it gets on"* [1]. These problems were likely worsened by the fact that the dust was electrically charged, which affected its adhesive and cohesive properties.

NASA's Requirements for Lunar Exploration Program (RLEP) Document (ESMD-RQ-0014) states that it shall investigate the potential impacts of the lunar dust environment [2]. Dust mitigation has also been identified as a priority for Mars exploration (MEPAG). Highlighted are the three main problems areas relating to electrically-charged dust: (1) Dust Adhesion and Abrasion, (2) Surface Electric Fields and (3) Dust Transport. These phenomena are interrelated and must be well understood in order to minimize the impact of dust on future exploration. Recent calculations and future measurements relating to the potential dust hazard are discussed.

Properties of Lunar Dust: Lunar dust grains are ~70μm (too fine to see with the human eye), with 10–20% <20μm [3]. Grain shapes range from spherical to extremely angular [3]. Lunar dust has a low conductivity and so can retain electric charge.

Dust Impact on Astronauts: During Apollo, dust was brought into the Lunar Module after moonwalks, which on occasion affected astronaut vision and breathing [3]. Prolonged periods on the lunar surface could lead to chronic respiratory problems in astronauts due to micron-sized dust in their lungs [4].

Dust Adhesion and Abrasion: Dust adhered to Apollo spacesuits and equipment (e.g., the Lunar Rovers [1,3]) both mechanically and electrostatically. Mechanical adhesion was due to the barbed grain shapes, while electrostatic adhesion was caused by the attraction between electrically-charged dust and surfaces (i.e., similar to how a photocopier works). The abrasive effect of adhered dust wore through spacesuit fabric and increased friction at mechanical surfaces, thus drastically reducing the useful lifetime of equipment [1,3]. Recovery of Surveyor 3 parts during Apollo 12 revealed that dust accumulation and adhesion were heavier than anticipated [3].

Surface Electric Fields: Probe theory predicts lunar surface potentials of ~+10V on the dayside and ~−100V on the nightside [5,6]. In the solar wind, a "wake" forms downstream of the Moon, which causes large E-fields to form at the terminator [7].

Lunar Dust Transport: Data from the Apollo 17 Lunar Ejecta and Micrometeoroids (LEAM) experiment was dominated by energetic impacts from electrically charged dust [8]. Horizon glow and "streamers" from forward scattered sunlight were observed above the terminator by both surface landers and astronauts [9,10]. Near the surface (<1m) this was likely caused by levitating ~5μm dust grains, which were repelled from the like-charged surface [9,11]. 0.1μm-scale lunar dust was present sporadically at much higher-altitudes (~100km) [10,11,12]. Our model suggests that this dust was electrostatically "lofted" by the "dynamic dust fountain" effect [6], where charged dust grains follow ballistic trajectories, subsequent to being accelerated upwards through a narrow sheath region by the surface E-field. This dust could interfere with lunar-based astronomy and exploration activities [13].

Conclusions: In order to fully assess the potential hazards posed by electrically-charged dust to lunar exploration it will be necessary to: (1) take in situ measurements of dust and plasma in the lunar environment with modern instrumentation (2) develop theory and simulations to model the highly-complicated lunar surface-dust-plasma interactions [6]. Required measurements include: spatial distributions of dust in the exosphere as a function of altitude, zenith angle, etc [cf,9]; field and plasma (density and temperature) profiles above the surface; impacts from transported dust [cf,8]. The above can be achieved by fairly basic flight-proven instrumentation, such as LIDARs, photometers, electron/ion detectors, etc. These measurements would resolve the ambiguities and uncertainties associated with the Apollo-era observations. Further development of our theoretical work will be needed in order to interpret these important and exciting new results [6].

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SUPERBOTS ON THE LUNAR SURFACE: MINI-MOBILE INVESTIGATION SYSTEM (MINI-MIS).
G.J. Taylor[1], R.C.F. Lentz[1], S.J.. Lawrence[1], L.M. Martel[1], W.-M. Shen[2], P.M. Will[2], M.H. Sims[3], S. Colombano[3], D. Kortenkamp[4], B. Damer[5], W. Chun[6]; [1]HIGP, University of Hawaii, Honolulu, HI 96822; gjtaylor@higp.hawaii.edu; [2]ISI, University of Southern California, LA, CA; [3]NASA AMES Research Center, Mountain View, CA; [4]Metrica, Houston, TX; [5]DigitalSpace, Santa Cruz, CA; [6]Lockheed-Martin Corp, Denver, CO.

Introduction: SuperBots are autonomous robotic modules that can *self*-reconfigure into different systems for different tasks [1]. An elegant example of "design for reuse" they can reduce cost and payload mass of a mission while enhancing performance, reliability, and safety. SuperBot modules and systems can be used to accomplish an enormous range of tasks [e.g. 2,3].

The Mini-MIS concept: One particularly appealing near- and long-term application is to use SuperBots as small, inexpensive, highly capable mobile platforms for science investigations. We call the concept Mini-Mobile Investigation System (Mini-MIS). The fundamental idea is that sets of 8 to 10 SuperBot modules would reconfigure to form a mobile platform with a specialized science or exploration device included inside a module or attached as a separate specialized module. The module set (Mini-MIS) would be able to reconfigure itself depending on the mobility or instrument deployment needs: wheels (for efficient travel), spiders or centipedes (for climbing), snakes (for burrowing), towers for communications (Fig. 1).

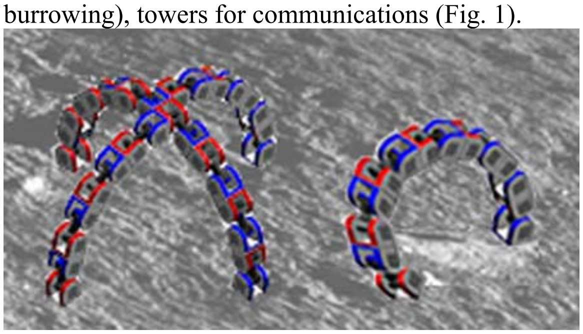

Fig. 1. Two configurations of Mini-MIS, each equipped with a specialized module (buried) for scientific observations or other exploration functions.

Mini-MIS modules can combine in a variety of ways as they move across the lunar surface. For delivery to the Moon, they can be efficiently packed into cubes, or disseminated throughout a lander. For deployment, the modules would assemble into one or more Mini-MIS platforms and crawl off the lander autonomously. We highlight below some near-term investigations where the Mini-MIS can greatly enhance lunar exploration.

Polar Explorer: The lunar Polar Regions are enriched in hydrogen [4], possibly in the form of H_2O ice trapped in permanently shadowed regions. This may constitute a valuable resource for propellant production on the Moon. However, the abundance, form (crystalline or amorphous ice), concentrations of impurities (CH_4, CO, NH_3, etc.), and spatial distribution of the H_2O are not known. Prospecting for the resource requires measurements in more than one location to provide a statistically-sound sampling of a region. This implies a rover, yet mission budget constraints might prohibit a large, robust rover. Thus, a resource survey involving a lander in one location would be greatly enhanced by using SuperBots as inexpensive rovers that could carry specialized modules to search for water over distances of a few kilometers. Two Mini-MIS assemblages could move in orthogonal directions from a lander, sampling every 100-200 meters.

Active Seismic Surveyor: The structure of the upper few hundred meters of the lunar surface is not characterized quantitatively. We believe that a network of 6-10 Mini-MIS consisting of 6-8 Superbot modules, each with a specialized geophone attached, could autonomously deploy itself into multiple, reconfigurable lines or arrays to map the lunar subsurface. Small triggered explosives would be used as a source for seismic signals. The Mini-MIS seismic surveyor could map typical regolith areas and impact crater structures and deposits.

Resource Prospector: Mini-MIS could also carry a chemical analytical device to measure the concentration of marker elements for specific types of potentially useful deposits. Examples are measuring (1) the concentration of Zr, K, or P to find deposits rich in KREEP components, representing the last chemical remnants of the magma ocean (2) Cl or F to find enrichments of volatile sublimates in volcanic glass deposits.

Navigation Beacons: Mini-MIS could be used as beacons for local navigation on the lunar surface. A Mini-MIS beacon could climb a local hill to broadcast or relay signals, allowing astronauts to traverse in a rover out of sight of the lunar outpost.

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UNIQUE LUNAR SOIL PROPERTIES FOR ISRU MICROWAVE PROCESSING. Lawrence A. Taylor (lataylor@utk.edu), Edward Hill, and Yang Liu; Planetary Geosciences Institute, Department of Earth & Planetary Sciences, University of Tennessee, Knoxville, TN 37996.

Introduction: Most materials for near-lunar and on-the-Moon constructions will necessitate the active use of the resources of the Moon, resources that can be derived from the regolith (soil). The soil has been produced by micro-meteorite impacts occurring over eons, with processes that have produced some newly discovered, unusual, and unique properties in the soil [e.g., 1-3].

Lunar Soil placed in your Kitchen Microwave will Melt at ~1200 ^{0}C BEFORE your Tea Water will Boil at 100 ^{0}C.

Discussion: This unusual and unpredictable property of lunar soil is due to the presence of the abundant nanophase metallic Fe (Fig. 1) that is prevalent on all the impact-produced agglutinitic glass and the vapor-deposited np-Fe present on most of the soil-particle surfaces (Taylor et al., 2001). These minute, yet separated, metallic Fe grains readily couple with the 2.45 GHz microwaves in a simple Sears microwave oven. The position of much of the Fe^0 on the surfaces of grains, imparts the unique ability for local high-temperature domains at grain boundaries, such that the sintering actually involves the production of melt at the interfaces. Microwaved, pre-compacted as well as hot-pressed forms are relatively easy to produce.

The unique np-Fe feature imparts certain properties to the soil that make it an excellent feedstock for numerous ISRU purposes. Among these is the production of finished structural and mechanical forms with high strength and relatively low density (~2.5 g/cc). As shown in the cartoon in Figure 2, *other products that microwave processing can result in are only restricted to the depth of one's imagination* – from microwave-formed roads, **to** large-smooth parabolic antennae, **to** fabrication of structural products, **to** gardening large masses of hydrogen from the lunar soil, **to** oxygen production, et cetera. All these products involve the microwave heating of the fine fraction of the lunar soil, recalling that 50% of the lunar soil is ~ <50 µm.

References:

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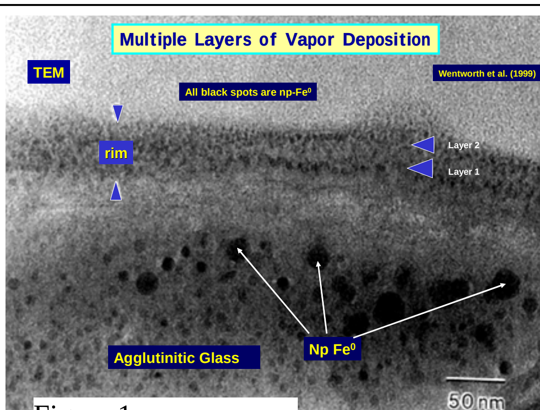


Figure 1.

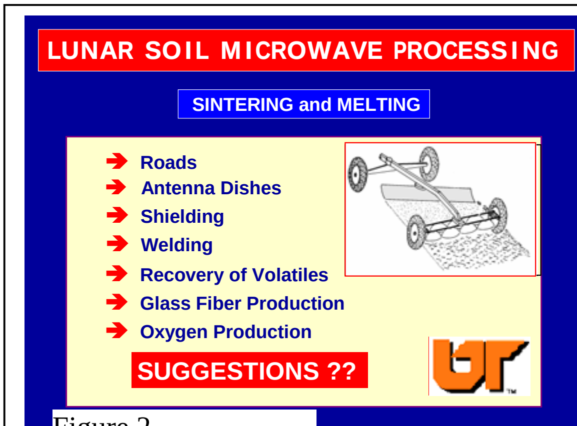


Figure 2.

ENABLING THE EXPLORATION VISION: NASA GOALS AND A LIBRATION POINT "GATEWAY".
H. A. Thronson[1], D. Lester[2], J. J. Watson[3], and R. Moe[4] [1]Science Mission Directorate, NASA Headquarters, Washington, DC 20546, [2]Department of Astronomy, University of Texas, Austin, TX 78712, [3]NASA Langley Research Center, Hampton, VA, and [4]Hubble Space Telescope Development Project, NASA Goddard Space Flight Center, Greenbelt MD 20771,

Introduction: Priority goals for NASA derived from the *Vision for Space Exploration* include the search for life throughout the Solar System, traveling among the Earth, Moon, and Mars with humans and robots, and developing the technological capabilities, such as *in situ* resource utilization, to undertake these challenges more effectively and safely. Consequently, several groups have assessed architectures that achieve multiple national goals in space with a modest number of elements; that is, concepts that can simultaneously serve multiple NASA missions. In this presentation, we discuss the latest operational concept for a human-occupied "gateway" at the Earth-Moon L_1 point, which is intended to support lunar surface operations, enable the construction of large science facilities in space, and be a site for the development of bioastronautics capabilities when the ISS is no longer available.

Background: Ambitious plans for human and robotic exploration will require improved in-space capabilities building upon and significantly extending those developed for ISS and *Hubble* servicing. For example, surface operations on the Moon may require (or enable) space depoting of supplies during the same period that preparation for sending humans to Mars will use in-space assembly and space demonstration missions. Given the variety of major goals in space, it is important to consider capabilities that can serve multiple goals.

For the past several years NASA, academic, and industrial teams have been assessing a post-ISS, human-occupied "gateway," often proposed for the first Earth-Moon libration point. This concept was first developed by NASA's Decade Planning Team and highlighted at the *Loya Jirga* in-space concepts workshops, reported elsewhere. [See references 1, 2,]

The "Gateway" Concept of Operations:

Necessity for human operations in space. It seems essential that humans will have to extend capabilities in free space for decades into the future: support for lunar surface operations, the assembly of very large optical systems and other science facilities in space, and the preparation to travel to Mars (bioastronautics, space wellness, human-occupied precursor and demonstration systems).

A "gateway" concept for ~2020. "Gateways" of various kinds have been presented and discussed for some years. Essential to their operation has been the capability to serve multiple purposes with a single facility. In early concepts, the "gateway" was single-launched via Shuttle or EELV, then transported to its final location via a chemical transfer stage or solar-electric tug. The most popular location considered for the "gateway" has been the Earth-Moon L_1 point because of its attractiveness for dynamic access to multiple space and lunar surface locations. Libration point locations are not, however, a requirement.

In the current concept for the "gateway," a single heavy-lift launch to low Earth orbit is able to place an inflatable facility that will have ~1/3 the volume of the completed ISS. A solar electric tug can place this facility in whatever location that is necessary to support national goals. Depending upon the mission, 4 – 6 astronauts can occupy the "gateway" for up to a month without re-supply, with a series of users over time increasing the capabilities of the facility.

In addition to enabling in-space construction and lunar surface support, a "gateway" may become the Block 1 version of the habitation module for human missions to Mars. That is, while supporting near-term lunar and Earth-Moon free space goals, the "gateway" can also be the demonstration and validation facility for sending humans to Mars.

Precursors to a "gateway." Extravehicular and in-space telerobotic operations in space appear to be necessary to achieve NASA goals in the time period in advance of a highly capable "gateway" and human missions to Mars. For that reason, upgrades to the Crew Exploration Vehicle for limited telerobotics capabilities in free space have been considered.

References: [1] Lester, D., Freidman, E. and Lillie, C. (2005) *SPIE Conference Proceedings* Contribution 5899-21, in press. [2] Moe, R. *et alia*, (2005), *AIAA First Exploration Conference*, in press.

INITIATING AN INTERPLANETARY He-3 ECONOMY WITH LUNAR PROPELLANT GENERATION AND IN-SITU RESOURCE EXPLORATION .

J. E. Van Cleve[1], R. Reinert[1], J. F. Santarius[2], G. L. Kulcinski[2], Brad Blair[3]. [1]Ball Aerospace & Technologies Corp. (1600 Commerce St., Boulder CO 80301, jvanclev@ball.com) [2] Univ. of Wisconsin (1500 Engineering Dr., Madison, WI 53706) [3]Colorado School of Mines (1500 Illinois St., Golden, Colorado 80401)

Introduction: We present the initial development of an integrated space transportation and energy architecture of a self-sustaining interplanetary economy based on extraction of Helium-3 (^{3}He) for fusion power and propulsion. While no single element of this architecture is entirely new, our contribution is the synergistic space transportation and energy architecture, shown in Figure 1, which provides a practical and sustainable path to a revolutionary D-^{3}He powered future on earth and in space. In this talk, we will progressively focus our vision from spanning the Solar System and centuries of time to recommended payloads for the first lunar landing missions of this epoch of Exploration, in the years 2010-2012.

Lunar Resources Enable This Architecture: The Moon is the key to this architecture, as it is for the Exploration Vision in general, since

1. The Moon contains enough ^{3}He in adequate concentration to supply initial demand for terrestrial power generation and justify the resources to develop ^{3}He reactors.
2. The Moon is 2000x closer to Earth than the other reservoirs of ^{3}He, the outer planets, vastly simplifying repair, resupply, and rescue operations.
3. The Moon has LOX/LH_2 resources for propellant for high thrust/mass (>1 ms^{-2}) transportation needed to move cargo to and from the lunar surface.

The ^{3}He Extraction Architecture Implies Goals for Near-Term Robotic Lunar Exploration: While elements of this economy are in the distant future, the first steps are within the planning horizon of lunar exploration, between now and 2020:

1. Locate highest concentrations of 3He, hydrogen, and oxygenic minerals. Polar ice deposits would be a windfall but are not necessary
2. Field-test extraction methods

The next step, building a positive mass flow lunar H_2O economy, is analyzed with a detailed mass flow model connecting mining operations, lunar bases, the lunar Lagrange point, LEO, and the Earth's surface to show a reduction of launch mass by a factor of 4 or more.

Robotic Lunar Exploration Goals Lead to Site Selection, Measurement Objectives, and Payloads for the First Lunar Landers: In pursuit of lunar water, we identify and discuss landing sites near Shackleton Crater which meet the requirements of

1. Solar illumination for >60 days during Solstice
2. Line of Sight to Earth for communication >14 days
3. Adjacent to cold traps which may contain water.
4. Less than 15 degree slope for landing.

We discuss a notional payload suite to characterize the cold trap and adjacent regions, including a water-detection instrument ("Water Boy") which can be shot out of a mortar from the lander in sunlight to the regions of interest in perpetual darkness. Based on the work of Vasavada et al. [1], this distance can be as small as 2 km. "Water Boy" payloads may also be delivered from a magazine aboard an orbiting bus, as described by Van Cleve and Mitchell [2]. Finally, we discuss searching for 3He on subsequent landed missions using active neutron spectroscopy.

References:

[1] Vasavada A. R. et al. (1999), *Icarus 141*, 179
[2] J. E. Van Cleve and S. Mitchell (2005), AAS 05-144[JVC1].

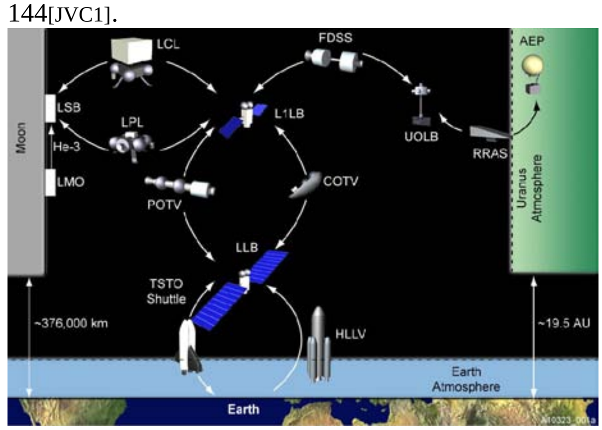


Figure 1: 3He Extraction and Space Transportation Architecture. Labels:

AEP	Aerostat Platform
COTV	Cargo Orbital Transfer Vehicle
FDSS	Fusion Deep Space Shuttle
HLLV	Heavy Lift Launch Vehicle
L1LB	L1 Logistics Base
LCL	Lunar Cargo Lander
LLB	LEO Logistics Base
LMO	Lunar Mining Operation
LPL	Lunar Personnel Lander
LSB	Lunar Surface Base
POTV	Personnel Orbital Transfer Vehicle
RRAS	Rocket/Ramjet Atmospheric Shuttle
TSTO	Two Stage To Orbit
UOLB	Uranus Orbital Logistics Base

IN-SITU SPACE BASED CONSTRUCTION USING TAILORED FORCE FIELDS. S. S. Wanis[1] and N. M. Komerath[2], [1]PhD Candidate in Aerospace Engineering (sameh_wanis@ae.gatech.edu), [2]Professor of Aerospace Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0150 (narayanan.komerath@ae.gatech.edu)

Introduction: The long-term potential of the Tailored Force Fields (TFF) project is that it explores a way to build large, massive infrastructure in Space. Such infrastructure is essential for permanent human habitats and extraterrestrial resource exploitation. The key technology enables automatic construction using solar energy and extraterrestrial material. The TFF concept arose from reduced-gravity flight test results [1] proving that large numbers of random-shaped objects placed in a standing acoustic wave field arrange themselves along discrete surfaces, corresponding to the predicted nodal surfaces of the acoustic field and may thus open the way for flexible fabrication. Theory and experiments from ultrasonics, optics and microwave regimes have been used to generalize this observation [2]. Long wavelength radio waves would be used for large scale construction. A 50m diameter, 50m high cylindrical module, shielded to 2m depth, was selected as an extreme test case. Results showed that the input power needed for such a radio-frequency resonator to construct structures on this scale are well within reason.

Space Structures: Several visionaries, Gerard O'Neill most prominent among them, argued that the best habitats for humans living away from earth to conduct space-based manufacturing, repair, supply and exploration, would be orbiting cities, rather than on or under planetary surfaces. In-depth studies were conducted by NASA/ASEE in the late 1970s. Contemporary humans need a gravity level near that found on Earth's surface (1G) for long-term living. Habitats built along the inner circumference of a rotating wheel or cylinder can simulate gravity to a desired extent. However, a current rule of thumb is that rotation rates must be below 1RPM to spare most people from disorientation. Thus, a wheel with 1G at the rim at less than 1 RPM, has a radius on the order of a kilometer. Building such a structure in space is a daunting undertaking.

Radiation shielding is the obstacle to plans for human exploration and development of space. Again, a thumb rule is that roughly 2m thickness of lunar regolith, or about 0.5m of water, is needed to effectively stop all forms of space radiation to the level needed to avoid limiting human tenure in space. A shield for a station large enough for long-term habitation is obviously too massive to contemplate launching from Earth, and there is a chicken-and-egg problem with using human labor to build the radiation shield. These problems have essentially killed off ambitions to build cities in space. The NASA/ASEE studies of 1977-79 reduced the original pressurized-sphere and cylinder designs and minimized exposed surface area with tubular-rim stations, but still found it impossible to build the radiation shields, even at the ludicrously-optimistic STS launch cost projection of $100/lb to LEO.

TFF Based Construction: Based on experimental evidence within a unifiying theoretical framework, TFF technology offers a solution to the problem of adequate long-term radiation shielding, by automatically forming raw construction material derived from low-gravity Near-Earth objects into useful structural shapes in space. Other implications are that the structures being conceived are large enough to enable 1G, spacious, safe shirtsleeves environments and large-volume storage. With such infrastructure in orbit, the present stranglehold of earth launch costs will be broken, and one can visualize a massive Space based economy that will dwarf today's terrestrial economy.

Test Case: Radiation Shield Architecture. We selected a 50m diameter, 50m high cylindrical module, shielded to 2m depth, as a test case, and estimated the input power needed to a radio-wave resonator in order to form such a module from a cloud of 20cm-diameter rocks. This power could be provided by a 2 square-kilometer, 10% efficient solar cell array. The power needed was much lower than that used by the Arrecibo radio telescope in the 1970s to beam a 3-minute signal into space as part of the SETI program.

References:

[1] Wanis S., Matos C. and Komerath N. (2000) *AIAA 00-1020, Aerospace Sciences Meeting, Reno, NV*. [2] Komerath N., Wanis S. and Czechowski J. (2003) *STAIF 02-084 conference proceedings*, edited by El-Genk.

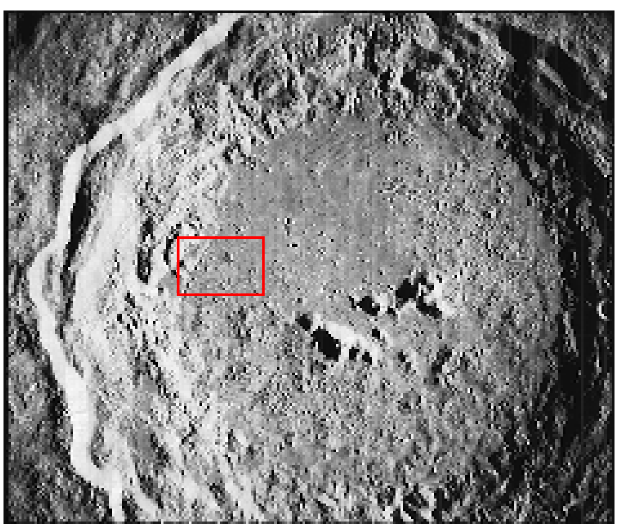
LUNAR ORBITER VERY HIGH-RESOLUTION VIEWS OF LUNAR APOLLO SITES OF INTEREST. L. Weller, T. Becker, L. Gaddis, D. Soltesz, D. Cook, A. Bennett, T. McDaniel, B. Redding, J. Richie, Astrogeology Team, U.S. Geological Survey, 2255 N. Gemini Drive, Flagstaff, AZ (lweller@usgs.gov).

Introduction: In conjunction with our recent work [1-5] to create a global digital mosaic of Lunar Orbiter (LO) photographic data [6, 7], we have scanned and processed a selected subset of the very high resolution (VHR) data acquired by LO-III and –V high- (HR) and medium-resolution (MR) cameras. These VHR views were obtained for numerous 'sites of interest' in preparation for the Apollo landings. The LO digital frame mosaics are being made available at reduced resolution on the following USGS Web site (http://astrogeology.usgs.gov/Projects/LunarOrbiterDigitization/statusmaps_veryhigh.html). In the coming year, we will release these digital data as PDS-compatible products.

Summary: At low altitude, LO missions III and V collected hundreds of high-quality VHR frames of the lunar near side equatorial region (**Figure 1**). Ground resolution of these data ranged from 1 to 5 m/pixel for the HR camera and 10 to 40 m/pixel for the MR camera. We have completed scanning a total of 164 LO VHR frames that fall within 10 areas photographed by LO III and 17 areas photographed by LO V. This total is ~20% of the VHR LO III and V data acquired. As with the global project, constructed VHR frames will be made available online following validation. These frames will be geometrically controlled to the final HR III, IV and V frames that are processed for the global mosaic. Geodetic control for these LO data is provided by the new, improved Unified Lunar Control Network 2005 [8, 9].

These VHR data of the lunar surface provide some of the most detailed views of soils, boulders, and other features on the surface of the Moon. These LO data provide an essential baseline for characterization of the lunar surface environment for future lunar landed missions.

References: [1] Gaddis et al. (2001), *LPS XXXII*, #1892. Lunar Orbiter Pilot Project: http://astrogeology.usgs.gov/Projects/LunarOrbiterDigitization/. [2] Gaddis et al. (2003), *LPS XXXIV*, #1459. [3] Becker et al. (2004), *LPS XXXV*, #1791. [4] Becker et al. (2005), *LPS XXXVI*, #1836. [5] Becker et al., this volume. [6] Hansen (1970), NASA SP-242. [7] Bowker and Hughes, (1971), NASA SP-206. [8] Archinal et al. (2005), LPS XXXVI, #2106. [9] Archinal et al. this volume.



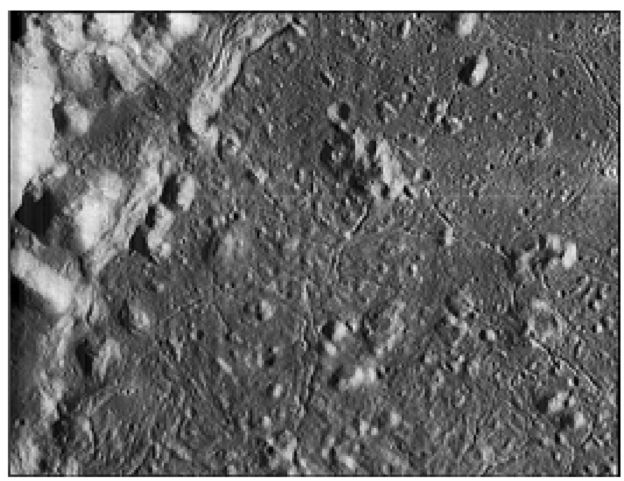


Figure 1. (Left) Mosaic of LO-V Frame 152M showing interior and a portion of the rim of Copernicus crater. (Right) LO-V Frame 152H3 showing very high-resolution view of the floor of Copernicus crater (centered on the red box in the figure at left). Note drapey texture of impact melts.

PHYSICS AND ASTROPHYSICS FROM THE MOON. T. L. Wilson, NASA, Johnson Space Center, Code KR, Houston, Texas 77058.

Introduction: Science on and from the Moon has important implications for expanding human knowledge and understanding, a prospect for the 21st Century that has been has been under discussion for some time [1-3]. That having been said, however, there remain many issues of international versus national priorities, strategy, economy, and politics that come into play. The result is a very complex form of human behavior where science and exploration take center stage, but many other important options are sacrificed. To renew this dialogue, several guidelines seem pertinent.

Methodology and Criteria for discussion: The references [1-3] are replete with examples of new science that can be accomplished using observatories, detectors, and measurements from the lunar surface. The purpose here is not to expound on or add to that list, although it will be indirectly addressed.

The first criterion is a question. What does one mean by a return to the Moon? The answer to this will be assumed here as: to establish a permanent human presence there. Without such a commitment, national or international, the strategy and architecture for advancing science is greatly compromised. Robotic exploration has accomplished wonders by Earth-based observers using telescience, and Earth-obiting satellites have made countless discoveries. Why take humans to the Moon? A counterargument against a permanent human presence is to use the Moon only as a temporary stepping stone for Mars exploration.

The second criterion is also a question. Why are we humans doing this? The answer is not the proverbial one of having a space race between astronauts and cosmonauts, or for national defense, or because the Moon is there. The answer adopted here will be the same one used by U.S. physicists while attempting to justify construction of the Superconducting Super Collider (SSC) twenty years ago. Grand-scale, flagship enterprises are the forum for inspiring and educating tomorrow's generations of young people in the pursuit of human understanding. Science through space exploration is such a goal.

The third criterion is another question. Should NASA be doing the science part of such exploration instead of partnering with some other agency? There already exist examples of partnerships, one being the Alpha Magnetic Spectrometer (AMS) in collaboration with the Department of Energy (DOE) and international investigators in high-energy physics (HEP) [4].

Permanent Moon Base: Serious architectures for lunar exploration involve at least one lunar base that constitutes a permanent human presence. Someone is on the Moon at all times. The virtue of this evolutionary result is that other aspects of science than geoscience can be investigated. Not everyone thinks that geology is most important, except in the initial or preliminary phase of exploration. Other science can be conducted in the shirt-sleeve environments of laboratories and observatories of a permanent Moon base. Traditional NASA lunar exploration studies, nevertheless, have no strategic answer to the funding source for such science as an astronomical array or HEP laboratory on the Moon. Who pays and why must it be NASA? This is the mature phase of lunar exploration where real science begins to receive its greatest rewards. Except for telescience and robotics, NASA is primarily in the business of space transportation and habitation infrastructure and not ground-based measurements save geological ones. Perhaps conventional non-NASA agencies should bear responsibility for ground-based observatories and laboratories on the Moon. The existing cultural paradigm is that NASA pays and that can be in direct conflict with science funding for other government resources.

Fundamental Physics: There are compelling arguments for establishing science on the Moon as one of the primary goals for returning to the Moon and venturing beyond. A number of fundamental physics experiments are background-limited by the Earth's magnetic dipole moment, and noise produced by its atmosphere and seismic interior. Candidate experiments vary from neutrino and gravitational wave astronomy, particle astrophysics, and cosmic-ray calorimeters, to space physics and fundamental physics such as proton decay [2, 3].

Conclusions: The present generation of proposals for science from and on the Moon [1-3], plus new ones, may witness a place in space exploration's future. It is clear, however, that NASA has not thought this through adequately. Such planning is the Agency's responsibility and not that of the individual investigators [5].

References: [1] Mendell W. W. (1985) *Lunar Bases and Space Activities of the 21st Century,* Lunar and Planetary Institute, Houston. [2] Potter A. E. and Wilson T. L. (1990) *Physics and Astrophysics from a Lunar Base,* AIP Conf. Proc. **202**, American Institute of Physics, New York. [3] Mumma M. J. and Smith H. J. (1990) *Astrophysics from the Moon,* AIP Conf. Proc. **207**, American Institute of Physics, New York. [4] Battiston R. (2002) *Intl. J. Mod. Phys.* **A17**, 1589. [5] Wilson T. L. in Ref. 3, 608-621.

Active Solid State Dosimetry for Lunar EVA. J.D. Wrbanek,[1] G.C. Fralick,[1] S.Y. Wrbanek[1] and L.Y. Chen[2] [1]NASA Glenn Research Center, Instrumentation & Controls Division, Cleveland, Ohio. [2]Ohio Aerospace Institute, Brook Park, Ohio.

Introduction: The primary threat to astronauts from space radiation is high-energy charged particles, such as electrons, protons, alpha and heavier particles, originating from galactic cosmic radiation (GCR), solar particle events (SPEs) and trapped radiation belts in Earth orbit. There is also the added threat of secondary neutrons generated as the space radiation interacts with atmosphere, soil and structural materials.[1]

For Lunar exploration missions, the habitats and transfer vehicles are expected to provide shielding from standard background radiation. Unfortunately, the Lunar Extravehicular Activity (EVA) suit is not expected to afford such shielding. Astronauts need to be aware of potentially hazardous conditions in their immediate area on EVA before a health and hardware risk arises. These conditions would include fluctuations of the local radiation field due to changes in the space radiation field and unknown variations in the local surface composition. Should undue exposure occur, knowledge of the dynamic intensity conditions during the exposure will allow more precise diagnostic assessment of the potential health risk to the exposed individual.[2]

Technology Need: An active personal dosimeter for Low Earth Orbit (LEO) EVA use is specifically recommended by NASA JSC's Radiation Dosimetry Working Group, and the National Council on Radiation Protection and Measurements (NCRP) recommends personal radiation monitoring for real-time dose rate and integrated dose in LEO.[3] Compared to the current LEO missions, the expeditions to the Moon will place crews at a significantly increased risk of hazardous radiation exposure.

Current radiation measurement and warning systems may be not adequate for the future Lunar missions, and currently instruments do not exist that can make these measurements and be incorporated into the Lunar EVA suit. However, MEMS devices fabricated from silicon carbide (SiC) to conduct low-noise neutron and alpha particle spectrometry have recently been reported outside of the context of personal dosimetry.[4]

Development Effort: NASA GRC has been leading the world in the development of SiC semiconductor technology, producing SiC semiconductor surfaces of much higher quality than commercially available, as shown in figure 1. These surfaces have demonstrated advantages over standard materials for other sensor applications.[5] In other activities, NASA GRC is attempting to verify claims of nuclear energy in sonoluminescence using thin film coated scintillation detectors fabricated at NASA GRC as part of the Vehicle Systems Program, shown in figure 2.[6]

NASA GRC is leveraging these efforts to investigate small and large area MEMS devices for sensitivity to radiation and to compare with commercial devices. If these initial results look promising as a path for the design and fabrication of a prototype solid state dosimeter, further testing would be required in conjunction with other researchers in the space radiation field over the next few years. The long term objective of this effort is to provide a compact, low power active electronic dosimetry system that would not be adversely affected by radiation, with improved sensitivity and detection capability for real-time monitoring of Lunar EVA conditions.

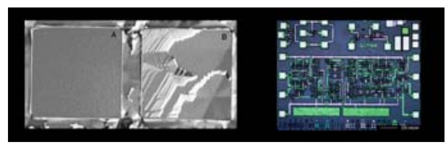


Figure 1: Examples of NASA GRC SiC Fabrication: Defect free (far left) & typical (center left) SiC surfaces, and a SiC circuit (right).

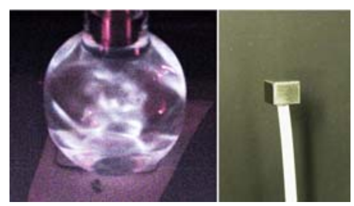


Figure 2: Radiation Detector Development: NASA GRC is attempting to verify claims of nuclear energy in sonoluminescence (left) using thin film coated scintillation detectors fabricated at NASA GRC (right).

References: [1] Johnson A.S., Badhwar G.D., Golightly M.J., Hardy A.C., Konradi A. and Yang T.C. (1993) *NASA TM-104782*. [2] R. Turner (2000) *LWS Community Workshop*. [3] Vetter R.J., et al. (2002) NCRP Report No. 142, 47-49. [4] Ruddy F.H., Dulloo A.R., Seidel J.G., Palmour J.W. and Singh R. (2003) *Nucl. Instr. and Meth. A 505*, 159–162. [5] Hunter G.W., Neudeck P.G., Xu J., Lucko D., Trunek A., Artale M., Lampard P., Androjna D., Makel D., Ward B. and Liu C.C. (2004) *Mat. Res. Soc. Symp. Proc. 815*, 287-297. [6] Wrbanek J.D., Fralick G.C., Wrbanek S.Y. and Weiland K.E. (2005) *NASA TM-2005-213419*, 46-7.

THE MARS GASHOPPER AIRPLANE. Robert Zubrin, Dan Harber, Gary Snyder, James Kilgore, Kyle Johnson, and Nick Jameson Pioneer Astronautics, 11111 W. 8th Ave. unit A, Lakewood, CO 80215, zubrin@aol.com

Introduction: The Mars Gas Hopper Airplane, or "gashopper" is a novel concept for propulsion of a robust Mars flight and surface exploration vehicle that utilizes indigenous CO_2 propellant to enable greatly enhanced mobility. The gashopper will first retrieve CO_2 gas from the Martian environment to store it in liquid form at a pressure of about 10 bar. When enough CO_2 is stored to make a substantial flight to another Mars site, a hot pellet bed is heated to ~1000 K and the CO_2 propellant is warmed to ~300 K to pressurize the tank to ~65 bar. A valve is then opened, allowing the liquid CO_2 to pass through the hot pellet bed that heats and gasifies the CO_2 for propulsion. The hot gas is piped to a set of thrusters beneath the aircraft, allowing vertical takeoff, after which the gas is shunted off to a primary rearward pointing thruster to generate forward flight speed. The hot gas system is also used for attitude control and main propulsion during landing.

After landing a microrover would be released for local exploration for a period of about a month, during which time the Gashopper would acquire more propellant to enable its next flight. The advantage of the Gashopper aircraft is that it provides Mars exploration with a fully controllable aerial reconnaissance vehicle that can repeatedly land and explore numerous widely separated surface sites as well.

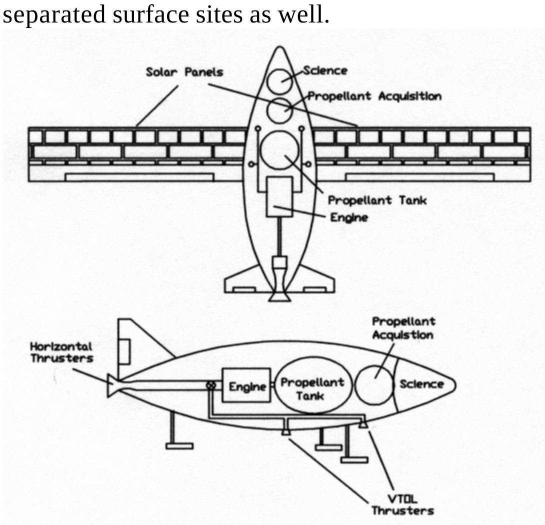


Fig. 1: The Mars gashopper airplane concept

This paper describes work accomplished from January, 25 2005 through July, 25, 2005 on the Mars Gashopper Aircraft SBIR Phase I project, contract number NNL05AB04P. The primary goal of the Mars Gashopper Aircraft SBIR phase 1 effort was to demonstrate a proof of concept Gashopper Airplane at low altitude on Earth. Christopher Kuhl was the NASA COTR at NASA Langley Research Center, Robert Zubrin was the Principal Investigator for this program at Pioneer Astronautics, Gary Snyder was the controls and propulsion subsystem engineer, Dan Harber was the Aerodynamics and Structures subsystem engineer, James Kilgore was the lead machinist, Kyle Johnson and Nick Jameson were hardware and mechanisms engineers.

Fig. 2: Vertical hover Gashopper flight test

Fig. 3: Gashopper Airplane flight test

Work performed during Phase I included technical analysis on the overall gashopper propulsion system performance, trade studies on thermal bed materials, and design of a full scale gashopper aircraft relative to the size of a Mars vehicle. Analysis showed that practical gashopper airplanes can be built capable of flights of over 100 km per hop on Mars. Phase I demonstration included successful engine tests to achieve required thrust levels, successful demonstration of a hovering gashopper, flight of a subscale gashopper aircraft, and a successful demonstration of a full scale gashopper airplane in horizontal flight.

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