CONCEPT STUDY FOR AN AUTONOMOUS LUNAR GEOPHYSICAL EXPERIMENT PACKAGE (ALGEP). W. B. Banerdt[1], M. A. Jones[1], L. Herrell[1], R. Miyake[1], S. Kondos[1], P. Timmerman[1], D. Albert[2], T. Chui[1], P. Davis[3], V. Dehant[4], C. L. Johnson[5], K. Khurana[3], P. Lognonne[6], M. Manga[7], M. Moldwin[3], P. Morgan[8], Y. Nakamura[9], C. Neal[10], J. Oberst[11], H.-J. Paik[12], C. Russell[3], G. Schubert[3], S. Smrekar[1], T. Spohn[11], and M. Wieczorek[12]. [1]Jet Propulsion Laboratory, California Institute of Technology (M.S. 264-422, 4800 Oak Grove Dr., Pasadena, CA 91109, bruce.banerdt@jpl.nasa.gov), [2]Army Corps of Engineers Cold Regions Research and Engineering Laboratory, Hanover, NH, [3]Univ. California Los Angeles, [4]Royal Observatory of Belgium, [5]Univ. British Columbia, [6]Inst. de Physique du Globe de Paris, [7]Univ. California Berkeley, [8]Northern Arizona Univ., [9]Univ. Texas Austin, [10]Notre Dame Univ., [11]DLR Institute of Planetary Research, [11]Univ. Maryland.

Introduction: The geophysical exploration of the interior structure and processes of the Moon has been recognized as a high scientific priority from the time of the Apollo project planning to the present [1]. The Apollo Lunar Surface Experiments Package (ALSEP) that was deployed by the later Apollo missions was enormously successful in furthering our understanding of the Moon and its history through seismic, magnetic, and geothermal measurements. Thirty years later, these data still largely define our knowledge of the Moon beneath its visible surface. By modern standards, however, this information is quite limited due both to the technology of the instrumentation available at the time and by the limited geographic extent of the Apollo landing sites.

The scientific questions that can be addressed by a network of geophysical packages have been presented previously [see, e.g., 2]. In this presentation we will concentrate on the technical aspects of implementing such a package in the context of the human exploration of the Moon.

Apollo-Era Geophysical Packages: ALSEP experiments were deployed on the Moon by Apollos 12, 14-17 during the period 1969-1972 [3]. They included various versions of the following geophysical instruments: Active Seismic Experiment (ASE), Passive Seismic Experiment (PSE), Lunar Surface Magnetometer (LSM), Heat Flow Experiment (HFE), and Laser Ranging Retroreflector (LRRR). The instruments were deployed on the lunar surface by astronauts in a "hub and spoke" configuration (Figure 1). The central unit, containing the command and data handling and telecom subsystems, was located in the hub position. The instruments and power source were fanned out around the central unit at distances and consistent with science requirements and were connected to the central unit through power and data lines (with the exception of the LRRR which required no connection). The power source was a radioisotope thermoelectric generator (RTG) which provided constant power for continuous operation of instruments through the night (approximately two weeks long in equatorial regions). Many of the packages continued to operate well beyond their one-year design life, up to eight years. Data acquisition from the packages was terminated in 1977.

A Contemporary Lunar Geophysical Package: In this study, we investigate a modern-day equivalent of ALSEP. The Autonomous Lunar Geophysical Experiment Package (ALGEP) will contain similar instruments to ALSEP including a very-broad-band seismometer, a shallow seismic sounder, a magnetometer, a heat flow probe and a laser retroreflector. We take advantage of thirty years of technology development on these instruments which has increased sensitivity while reducing required power and size of the sensors and accompanying accessories. This miniaturization, reduced power requirement and increase capability also applies to the telecom and command and data handling subsystems.

An approximately five-fold increase solar cell efficiency and overall reduced power requirements at the system level allow for the reevaluation of the trade between solar arrays and nuclear power sources. Due to increased complexity, uncertainties in availability, and astronaut safety, we have baselined solar arrays for ALGEP. The package is designed to accommodate conditions over a large range of locations on the lunar surface (far side excluded unless an orbital assest is in place) using solar arrays. The arrays and batteries are sized to allow for night operations of the science instruments, even in equatorial regions where night can last approximately two weeks, but constrained in size to allow for relatively easy deployment by an astronaut. Operational scenarios for day and night operations are being evaluated.

Technology enhancements provide the option of using modular platforms. Each instrument could be outfitted with its own miniaturized central unit containing power, telecom (to a base station), command and data handling, and thermal subsystems. A base station provides for overall control and communication with the Earth. The units are modular in that each miniaturized subsystem module would be designed to accommodate the needs of any of the instruments in the ALGEP package (Figure 2). All that is required is a simple and short connection between the subsystems module and the instrument. This concept deviates from the hub and spoke concept (Figure 1) in that the distribution of the instruments is not dependent on the length of the power or command and data handling lines that must connect each of the instruments to the central station. The instruments can be deployed long distances from each other if desirable and are essentially wireless. This concept has the potential to decrease deployment complexity and risk and increases astronaut safety.

The package will be design to accommodate approximately a six year lifetime. This allows for the ability to use sequentially deployed packages as a geophysical network, which greatly increases the value of the science return.

Subsystem Trades: Analysis of trades for the following subsystems are being performed to bound the ALGEP constraints in the following critical areas:

Power and Thermal. The nighttime requirements for a battery and solar array system can drive up the system mass, volume, and complexity. A positive feedback is created by battery heater loads at night, forcing increased sizing, use of phase change material (PCM) or use of radioisotope heating units (RHUs are not baselined but will be investigated). This problem may be addressed if the battery and potentially the instrument is buried in the regolith. By placing the battery 0.5 meters below the surface, a stable operating temperature over the day/night cycle can be achieved without RHUs and phase change materials, although this places severe requirements on astronaut deployment. A multilayer insulation blanket can be placed over temperature sensitive assemblies on the surface to minimize the temperature and utilize the bulk average temperature (Apollo used this technique). In general, the basic thermal design isolates the electronics bus from the environment and uses a thermal radiator with a thermal louver to control the energy balance. An ALGEP system with distributed instruments (modular platforms) will require individual PCM assemblies.

The solar panel is integral with the thermal blanketing, providing modulation of high temperatures for electronics. The solar array designs being evaluated in this study including a parasol configuration (Figure 2) or a tent-like configuration. These configurations would use thin inverted metamorphic solar cell technology on a flexible blanket and provide the necessary thermal control and power generation.

Telecommunications. The telecom subsystem will have direct-to-Earth (DTE) capability through a medium-gain antenna as the baseline. However, UHF orbital relay capabilities will be analyzed should an orbital asset be in place. Low-power systems with relatively small antennas are being evaluated.

Command and Data Handling. An important trade for the command and data handling subsystem is the balance between data storage and number of downlinks required to return data back to Earth. This trade is especially important during night science operations where power will be at a premium. It is anticipated that at night the instruments will operate in a minimum power mode, sufficient for acquiring and storing highest priority science data, with onboard processing and downlink occurring only during daylight.

Conclusion: Results of trade analyses at the subsystem level as well as a system level description of the package outlining mass, volume, and power constraints of the conceptual ALGEP will be presented, as will operational scenarios resulting from the chosen architecture which provide the necessary support for the geophysical investigations.

References: [1] *Scientific Context for Exploration of the Moon*, NRC, 2007; [2] Banerdt et al., LPSC XXXIX, abs. #2228, 2008; [3] Apollo 12 Prelim. Sci. Rept., NASA SP-235, 1970, Apollo 14 Prelim. Sci. Rept., NASA SP-272, 1971, Apollo 15 Prelim. Sci. Rept., NASA SP-289, 1972, Apollo 16 Prelim. Sci. Rept., NASA SP-315, 1972, Apollo 17 Prelim. Sci. Rept., NASA SP-330, 1973, ALSEP Termination Report, NASA RP-1036.

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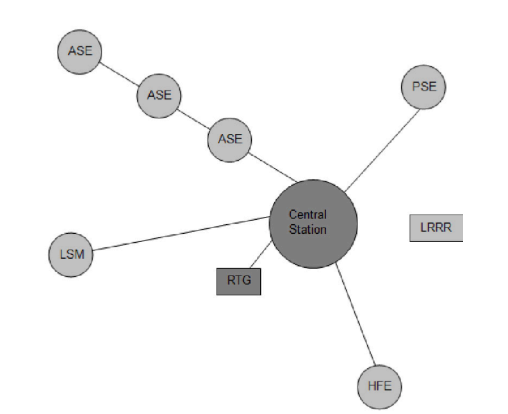

Fig. 1: Schematic diagram of the hub-and-spoke configuration used for the Apollo ALSEP Packages.

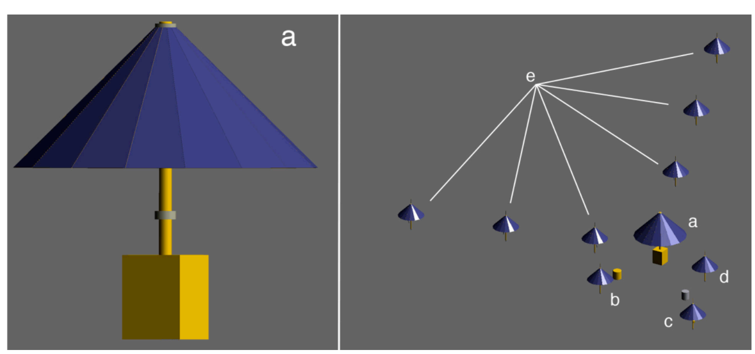

Fig. 2. One notional ALGEP configuration. Base station (a) contains overall communication and data acquisition and handling electronics; (b) seismometer, (c) heat flow probe, (d) magnetometer, and (e) seismic sounder geophones are distributed within line-of-sight distance of the base station on the lunar surface.