

## GERMANIUM GAMMA-RAY SENSOR

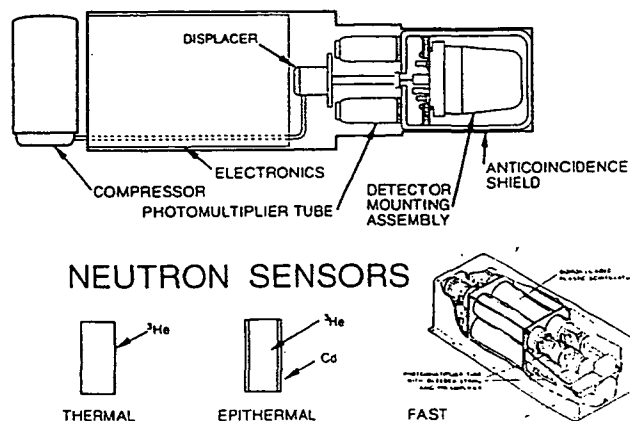


Fig. 1. Schematics of a generic germanium detector with a split-cycle Stirling cooler (adopted from [5]) and the neutron sensors for thermal, epithermal, and fast neutrons.

will eliminate most events due to charged particles, gamma rays produced by cosmic rays incident on the spacecraft, and Compton-scattered events in the crystal. A plastic scintillator over the nadir-pointing surface of the germanium crystal will provide a similar capability in the forward direction without significantly attenuating the gamma ray flux from the Moon. The gamma ray detector will be on a short cantilever to further reduce the background from the spacecraft. One side segment of the cesium iodide shield will serve as a back-up for the germanium crystal.

The critical issue for operating a germanium detector in space is the method of cooling. For short missions, stored cryogenics such as liquid nitrogen, solid methane, or solid argon have been proposed. For longer missions a passive radiator, such as used on the Mars Observer, or an active device, such as a Stirling cycle cooler, is required. We propose not to use a passive radiator because of complications in shielding the radiator from the Sun, Earth, and Moon when the spacecraft is in a polar orbit and, instead, propose to use the British Aerospace Stirling cycle cooler based on the Oxford design. This closed-cycle mechanical cooler is designed for a 10-year lifetime and has operated successfully in the laboratory without maintenance for over 2½ years. Two of these miniature cryocoolers were launched on 12 September 1991 as part of the Improved Stratospheric and Mesospheric Sounder (ISAMS) multichannel infrared radiometer on the Upper Atmosphere Research Satellite and are still operating successfully. Because the germanium detector energy resolution can be degraded by vibration, we plan to use a pair of these coolers with two compressors and two expanders mounted back to back to minimize vibration. In addition, we will use a flexible vibration decoupler between the expander cold tips and the germanium crystal. Microphonics should not be a problem because a germanium detector cooled by a cryocooler with a higher vibration level gave 3.6-keV resolution at 1332 keV, which is ~2 times worse than with a good laboratory Ge detector, but is more than adequate for planetary elemental mapping.

A neutron detector is required because it provides maximum sensitivity for hydrogen and hence water. Data from the gamma ray detector and the neutron detector are complementary because the neutron flux, which produces most gamma rays, can be used

to normalize the gamma ray line intensities; in turn, the gamma ray data are needed to determine the composition of the lunar surface and hence the moderation of neutrons by elements other than hydrogen [2]. Three different sensors are used to measure the neutrons in three energy ranges. Thermal neutrons ( $E_n \sim 0.010.4$  eV) are measured with a bare  $^3\text{He}$  proportional counter, epithermal neutrons ( $E_n \sim 0.4-10^3$  eV) with a  $^3\text{He}$  proportional counter wrapped with cadmium (which strongly absorbs thermal neutrons), and fast neutrons ( $E_n \sim 0.5-10$  MeV) with the backup Army Background Experiment (ABE) instrument, which contains four boron-loaded plastic scintillators [3]. Thermal/epithermal and fast/epithermal counting ratios are very sensitive to the amount of hydrogen in the lunar surface [4].

The gamma ray and neutron spectrometer will provide data on many elements over the entire lunar surface. Published estimates of the detection limits for similar detectors range from 0.016 ppm for uranium to 1.3% for calcium [5]. We estimate a hydrogen detection limit of 100 ppm based on this neutron detector system [4]. The spatial resolution is about  $140 \text{ km} \times 140 \text{ km}$ , which is determined by the orbit altitude of 100 km [6]. Both gamma rays and neutrons sense the elemental composition of the lunar surface to depths of tens of centimeters. The results from this instrument will complement the measurements from elemental and/or mineralogical remote sensing instruments with higher spatial resolution.

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References: [1] Edwards B. C. et al., this volume. [2] Reedy R. C. et al., this volume. [3] Feldman W. C. et al. (1991) *Nucl. Instrum. Meth. Phys. Res.*, A306, 350-365. [4] Feldman W. C. et al. (1991) *GRL*, 18, 2157-2160. [5] Metzger A. E. and Drake D. M. (1991) *JGR*, 96, 449-460. [6] Reedy R. C. et al. (1973) *JGR*, 78, 5847-5866.

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MAGNETIC SUSCEPTIBILITY MEASUREMENTS FOR IN SITU CHARACTERIZATION OF LUNAR SOIL. R. R. Oder, EXPORTech Company, Inc., New Kensington PA, USA.

Magnetic separation is a viable method for concentration of components of lunar soils and rocks for use as feedstocks for manufacture of metals, oxygen, and for recovery of volatiles such as  $^3\text{He}$  [1].

Work with lunar materials indicates that immature soils are the best candidates for magnetic beneficiation [2]. The magnetic susceptibility at which selected soil components such as anorthite, ilmenite, or metallic iron are separated is not affected by soil maturity, but the recovery of the concentrated components is. Increasing soil maturity lowers recovery [3]. This is illustrated in Fig. 1.

Mature soils contain significant amounts of glass-encased metallic iron. Magnetic susceptibility, which is sensitive to metallic iron content, can be used to measure soil maturity. The relationship between the ratio of magnetic susceptibility and iron oxide and the conventional maturity parameter,  $I_s/\text{FeO}$ , ferromagnetic resonant intensity divided by iron oxide content, is given in Fig. 2. The magnetic susceptibilities were determined using apparatus designed for magnetic separation of the lunar soils.

Magnetic susceptibility should be incorporated in the instrumentation packages carried by lunar landers and rovers for *in situ* identification of candidate soils best suited for magnetic benefi-

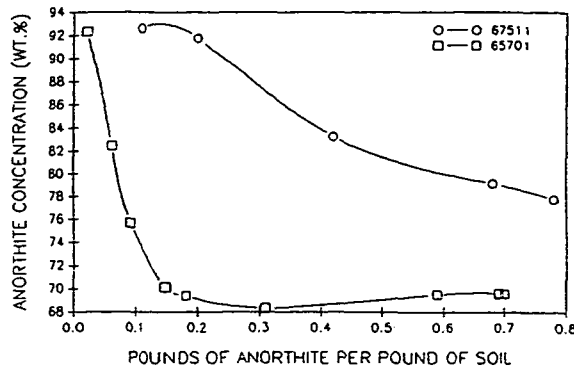
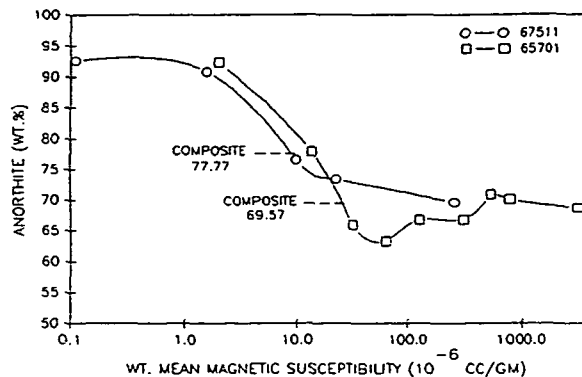


Fig. 1. Anorthite separation from highland soils.

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THE QUICKEST, LOWEST-COST LUNAR RESOURCE ASSESSMENT PROGRAM: INTEGRATED HIGH-TECH EARTH-BASED ASTRONOMY. Carlé M. Pieters and the PRELUDES Consortium, Brown University, Providence RI 02912, USA.

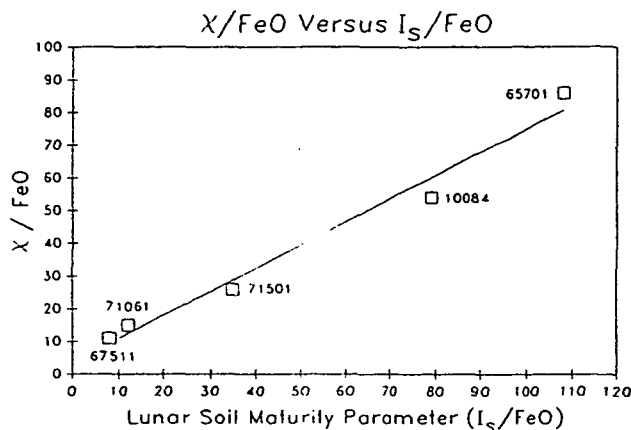


Fig. 2. X/FeO vs. soil maturity.

ciation. The measurement is more amenable to *in situ* measurement than is ferromagnetic resonance.

There are many ways to measure magnetic susceptibility that could be incorporated in mobile soil characterization packages. Instrumentation to detect separable ilmenite might combine magnetic susceptibility and X-ray methods to measure iron and titanium. Measurements could be made on soil samples or on core samples for rapid determination of maturity. This would permit a quick assessment of the potential for magnetic separation of selected mineral components.

References: [1] Oder R. R. et al. (1989) LPSC XX, 804-805; Oder R. R. and Taylor L. A. (1990) In *Engineering, Construction and Operations in Space II* (S. W. Johnson and J. P. Wetzell, eds.), 143-152, American Society of Civil Engineers, New York. [2] Oder R. R. and Jamison R. E. (1989) *Final Report, Phase I SBIR Program*, NASA Contract NAS 9-18092. [3] Oder R. R. (1991) *IEEE Transactions on Magnetics*; Oder R. R. (1991) AIME-SME Annual Meeting, Denver.

**Introduction and Recommendations:** Science and technology applications for the Moon have not fully kept pace with technical advancements in sensor development and analytical information extraction capabilities. Appropriate unanswered questions for the Moon abound, but until recently there has been little motivation (funding) to link sophisticated technical capabilities with specific measurement and analysis projects. Over the last decade enormous technical progress has been made in the development of (1) CCD photometric array detectors, (2) visible to near-infrared imaging spectrometers, (3) infrared spectroscopy, (4) high-resolution dual-polarization radar imaging at 3.5, 12, and 70 cm, and equally important, (5) data analysis and information extraction techniques using compact powerful computers. Parts of each of these have been tested separately, but there has been no programmatic effort to develop and optimize instruments to meet lunar science and resource assessment needs (e.g., specific wavelength range, resolution, etc.) nor to coordinate activities so that the symbiotic relation between different kinds of data can be fully realized. No single type of remotely acquired data completely characterizes the lunar environment, but there has been little opportunity for integration of diverse advanced sensor data for the Moon.

**Recommendation.** A research and analysis program to survey potential resource sites on the lunar nearside is recommended that would include aggressive instrument development and acquisition and analysis of advanced sensor data obtained for the Moon with optical, infrared, and radar telescopes. Coordinated acquisition and integration of advanced sensor data can provide synoptic information necessary to assess regional compositional diversity, local regolith character, and geologic context of sites on the lunar nearside that have high potential for lunar resources. The cost of such an R&A program is estimated to be about \$5 million per year. This program includes an instrument development and upgrade program during the first year, and calibration and initial data products by the second year. The broad nature of the program exercises expertise gained during and since Apollo and provides