

Fig. 3.

which is the concentration of fine-grained metal determined by ferromagnetic resonance ( $I_s$ ) normalized to the total iron content (as FeO) [1].  $I_s/FeO$  has been measured for virtually every soil returned by the Apollo and Luna missions to the Moon; values for surface soils are compiled by [2].

Because the technique is sensitive to both oxidation state and mineralogy, iron Mössbauer spectroscopy (FeMS) is a viable technique for *in situ* lunar resource assessment. Its utility for mineralogy is apparent from examination of published FeMS data for lunar samples [e.g., 3-5]. From the data published by [5], we can infer that FeMS data can also be used to determine soil maturity. We discuss here (1) the use of FeMS to determine mineralogy and maturity and (2) progress on development of a FeMS instrument for lunar surface use.

**Mineralogy and Maturity:** Figure 1 shows FeMS spectra for two Apollo 17 soils, 72131 and 73131. Even by visual inspection, the two soils have very different proportions of the ferrous-bearing minerals pyroxene, olivine, and ilmenite. From peak areas, the percentages of total iron associated with each of those mineralogies are 66, 15, and 16 for 72131 and 57, 39, and 4 for 73131. Thus, a Mössbauer spectrometer on a lunar rover could be used to prospect for ilmenite-rich soil horizons (deposits).

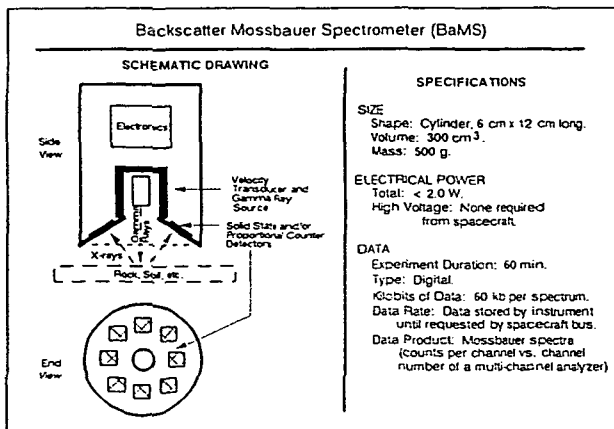


Fig. 4.

A reason for finding ilmenite deposits is shown in Fig. 2, which presents FeMS spectra for a crushed lunar rock (70035) both before and after reduction by hydrogen. The only two iron-bearing mineralogies present in the untreated rock are ilmenite and pyroxene, with 23% of the total Fe in the ilmenite. After H<sub>2</sub> reduction, there is no evidence in the FeMS spectra for ilmenite. Only metallic iron and pyroxene are present, which implies that reduction of ferrous iron in ilmenite is kinetically favored over that in pyroxene. The 36% area for Fe metal does indicate, however, that some of the ferrous iron in pyroxene has been reduced to metal.

In Fig. 3, we plot the excess area near zero velocity, which is a measure of the concentration of superparamagnetic Fe metal (sp-Fe<sup>0</sup>), as a function of the maturity index  $I_s/FeO$  for nine lunar samples. The area for sp-Fe<sup>0</sup> was calculated using the procedure of [5] except that no attempt was made to correct for saturation effects. A linear correlation is present, which demonstrates that maturity data can be derived from Mössbauer measurements.

**Instrument Development:** The current status of development of our backscatter Mössbauer spectrometer (BaMS) is described by [6]. A schematic of the instrument, together with specifications, is given in Fig. 4. The instrument has low mass, low volume, low power consumption, and low data transfer rate. We have built and fully tested the velocity drive. Operation in backscatter mode means that no sample preparation is required. The instrument can be placed on a lander or rover or used at a lunar base.

**References:** [1] Morris (1976) *Proc. LSC 7th*, 315. [2] Morris (1978) *Proc. LPSC 9th*, 2287. [3] Herzenberg et al. (1971) *Proc. LSC 2nd*, 2103. [4] Gibb et al. (1972) *Proc. LSC 3rd*, 2479. [5] Housley et al. (1974) *Proc. LSC 5th*, 2623. [6] Agresti et al. (1992) *Hyperfine Inter.*, in press.

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**GAMMA RAY AND NEUTRON SPECTROMETER FOR THE LUNAR RESOURCE MAPPER.** C. E. Moss, R. C. Byrd, D. M. Drake, W. C. Feldman, R. A. Martin, M. A. Merrigan, and R. C. Reedy, Los Alamos National Laboratory, Los Alamos NM 87545, USA.

One of the early Space Exploration Initiatives will be a lunar orbiter to map the elemental composition of the Moon. This mission will support further lunar exploration and habitation and will provide a valuable dataset for understanding lunar geological processes. The proposed payload will consist of the gamma ray and neutron spectrometer discussed here, an X-ray fluorescence imager [1], and possibly one or two other instruments. The spacecraft will have a mass of about 1000 kg including fuel, be built on a fast schedule (about three years), and have a low cost (about \$100 M including launch). Launch is tentatively scheduled for April 1995.

Most gamma rays used to map lunar elements are in the energy range of 0.2-8 MeV. The proposed gamma ray detector will contain an n-type germanium crystal that is ≈70% efficient [relative to a 7.62-cm-diameter x 7.62-cm-length NaI(Tl) scintillator]. N-type is used because it is much less susceptible to radiation damage than p-type germanium. Because a Stirling cycle cooler will be used, the crystal will be mounted using techniques commercially developed in recent years for operating germanium detectors on vibrating platforms. A segmented cesium iodide [CsI(Na)] anti-coincidence shield on the sides and back of the germanium crystal

## GERMANIUM GAMMA-RAY SENSOR

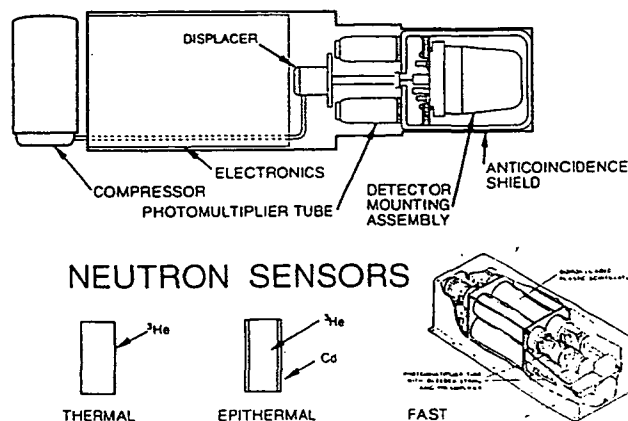


Fig. 1. Schematics of a generic germanium detector with a split-cycle Stirling cooler (adopted from [5]) and the neutron sensors for thermal, epithermal, and fast neutrons.

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-