could penetrate to depths of about 1 m. Sample volume of a few cubic centimeters from depth intervals of a few centimeters would be obtained. The auger would be housed in a tube such that samples from a given depth remain isolated from regolith material at other depths.

A physical properties payload would be intended to study the geotechnical properties of the surface and subsurface. Those data would be aimed primarily at engineering objectives but would also be applicable to geoscience problems. Parameters of interest include particle size and shape, density and porosity, compressibility, shear strength, bearing capacity, trafficability, electrical conductivity, and charging/discharging of the surface. The complete payload is under study and has not yet been determined. However, it is anticipated that an electron-magnetic sounding system would be used to determine the thickness, stratigraphy, and boulder content of the regolith. This system would be mounted on the rover body such that long distance or areally extensive traverses could be obtained.

Later Artemis landers have a larger payload capability, about 200 kg or larger. Additional studies are underway that consider the possibility of building larger rovers that have more capability, particularly with respect to lifetime, range, and drilling. Alternatively, the larger payload capacity could be used to deploy more of the small rovers outlined above.

COMBINED GAMMA RAY/NEUTRON SPECTROSCOPY FOR MAPPING LUNAR RESOURCES. R. C. Reedy, R. C. Byrd, D. M. Drake, W. C. Feldman, J. Masarik, and C. E. Moss, Space Science and Technology Division, Los Alamos National Laboratory, Los Alamos, NM 87545.

Some elements in the Moon can be resources, such as hydrogen and oxygen. Other elements, like Ti or the minerals in which they occur, such as ilmenite, could be used in processing lunar materials. Certain elements can also be used as tracers for other elements or lunar processes, such as hydrogen for mature regoliths with other solar-wind-implanted elements like helium, carbon, and nitrogen. A complete knowledge of the elemental composition of a lunar region is desirable both in identifying lunar resources and in lunar geochemical studies, which also helps in identifying and using lunar resources. Discussed here is the use of gamma ray and neutron spectroscopy together to determine abundances of many elements in the top few tens of centimeters of the lunar surface. To date, very few discussions of elemental mapping of planetary surfaces considered measurements of both gamma rays and the full range of neutron energies.

The concepts of using gamma rays or neutrons escaping from the Moon to determine lunar elemental composition date back over 30 years (e.g., [1]). In 1971 and 1972, gamma ray spectrometers (GRS) on Apollos 15 and 16 mapped ≈22% of the lunar surface but only could determine the abundances of several elements (Th, Fe, Ti, K, and Mg) because of the use of low-resolution NaI(Tl) scintillator detectors and the short durations of the missions. A high-resolution germanium GRS is on the Mars Observer scheduled to be launched in late September 1992 [2]. Such a spectrometer is much more sensitive for determining lunar elemental abundances and for identifying surface components than was the Apollo GRS [3]. Neutron spectroscopy of another planet has not been done yet, although the Mars Observer GRS is capable of detecting thermal and epithermal neutrons [2]. A germanium GRS can also detect neutrons ≥0.6 MeV by triangular-shaped peaks in the spectrum made by neutron-induced inelastic-scattering reactions in the detector [4]. The inclusion of a detector specifically designed to measure fast (E_n ~ 0.1–10 MeV) neutrons improves the sensitivity of detecting hydrogen in the lunar surface [5]. Spectrometers to measure the fluxes of gamma rays and neutrons escaping from the Moon are discussed elsewhere in this volume [6]. A gamma ray spectrometer can also be used to detect thermal and epithermal neutrons using coatings of thermal-neutron-absorbing materials [3], although not with the sensitivity of detectors designed specifically for such neutrons. The theories for gamma ray and neutron spectroscopy of the Moon and calculations of leakage fluxes are presented here with emphasis on why combined gamma ray/neutron spectroscopy is much more powerful than measuring either radiation alone.

Sources of Neutrons and Gamma Rays: Most gamma ray lines made by the decay of excited states in nuclei are produced by several types of nuclear reactions, mainly neutron nonelastic scattering and neutron capture [7–9]. The main exceptions are the gamma rays made by the decay of the naturally radioactive elements (K, Th, and U). The neutrons are made by the interaction of the energetic particles in the galactic cosmic rays (GCR) with the lunar surface [10]. Neutrons are produced mainly with energies of ~0.1–10 MeV, with some made with higher energies. The rates for the production of these fast neutrons depends on the intensity of the GCR particles, which can vary by a factor of ≈3 over an 11-year solar cycle [11], and is slightly (~5%) dependent on the surface composition [12]. The transport and interactions of these fast neutrons are also dependent on the surface composition. Neutrons in the Moon can be slowed by scattering reactions to epithermal (E_n ~ 0.5–10^3 eV) and thermal (E_n ~ 0.01–0.5 eV) energies. The flux of epithermal neutrons is mainly dependent on the hydrogen content of the surface, while the flux of thermal neutrons depends both on the amounts of neutron moderators like H and of thermal-neutron absorbers like Fe, Ti, Sm, and Gd [1,5,12,13]. Many neutrons escape from the lunar surface and can be detected in orbit. The gravitational field of the Moon affects slightly the flux at orbit of the lowest-energy neutrons [14].

The reaction of these neutrons with atomic nuclei in the lunar surface produces most of the gamma rays used for elemental mapping. Fast neutrons make gamma rays by a large variety of nonelastic-scattering reactions. Many elements (e.g., O, Mg, Si, and Fe) are mapped by neutron inelastic-scattering reactions making excited states in the target nucleus, such as $^{24}Mg(n,n\ \gamma)^{24}Mg$ exciting the 1.369-MeV state of ^{24}Mg (which almost immediately, ≲1 ps, decays to the ground state). Neutrons with energies of ~0.5–10 MeV make most of these inelastic-scattering gamma rays. Neutrons with higher energies can induce many types of reactions, such as the $^{28}Si(n,n\ \alpha\ \gamma)^{24}Mg$ reaction, which also can make the 1.369-MeV gamma ray. Many thermal and some epithermal neutrons produce gamma rays by neutron-capture reactions, such as the $^{28}Si(n,\gamma)^{29}Si$ reaction, which makes a cascade of gamma rays. The cross sections for neutron-capture reactions vary by orders of magnitude, and the elements mapped by gamma rays made by such reactions (e.g., Ti, Fe, and possibly Cl, Sm, and Gd) are those with high cross sections for (n,γ) reactions and that emit one or more gamma ray with a high yield per captured neutron.

Calculations of Neutron and Gamma Ray Fluxes: The ultimate sources of lunar neutrons and most lunar gamma rays are from interactions of the high-energy (E ~ 0.1–10 GeV) particles in the galactic cosmic rays. The Los Alamos high-energy transport

code LAHET is used to calculate the transport and interactions of the GCR particles and the production of secondary particles, especially neutrons. The LAHET code is based on the HETC code used by [12] but with additional physics included in the code, such as the production of neutrons by preequilibrium processes in excited nuclei. Neutrons with energies below 20 MeV are transported with the MCNP or ONEDANT codes. The ONEDANT code has been modified [14] to transport low-energy neutrons to orbital altitudes with consideration of gravity and the neutron's half-life. This series of codes is used to calculate the fluxes of neutrons escaping from the Moon. Preliminary results for neutrons escaping from the Moon were calculated by [5] using the ONEDANT code. As in [5], a range of lunar compositions and hydrogen contents has been examined with the LAHET/MCNP codes. The results of our calculations are consistent with those in [5] and show that taking ratios of the fast/epithermal and thermal/epithermal neutron fluxes is the best for determining both lunar hydrogen contents and the effective $1/v$ macroscopic cross section for the absorption of thermal neutrons in a lunar region.

To date, most studies of lunar gamma ray fluxes have used the values in [7,8]. In these works, the gamma ray fluxes from nonelastic-scattering reactions were calculated using the fast neutron fluxes of [10] and cross sections for producing specific gamma rays as a function of energy. The gamma ray fluxes from neutron-capture reactions were calculated with neutron-capture rates derived from [13] and evaluated nuclear data for gamma ray yields. Elemental detection sensitivities for a number of elements using both the Apollo Gamma Ray Spectrometer system and a high-resolution germanium spectrometer are given in [3]. Hydrogen is best measured using thermal, epithermal, and fast neutron spectrometers together with elemental abundances determined from a gamma ray spectrometer [5]. We are now in the process of coupling the neutron fluxes calculated with the codes discussed above with codes for the production and transport of gamma rays and will soon have new sets of elemental detection sensitivities using gamma ray and neutron spectrometers. For now, the calculated gamma ray fluxes of [8] are being used, as in the recent study by [3], which showed the great superiority of using high-resolution gamma ray spectrometers for lunar mapping.

Conclusions: The calculations for fluxes of neutrons escaping from the Moon have been extended and support the conclusions of [5] for using ratios of thermal, epithermal, and fast neutrons for lunar elemental studies. The fluxes of fast neutrons can vary by ~10% depending on the surface composition independent of the major variations expected from GCR-flux changes over a solar cycle. The direct measurement of the fluxes of fast neutrons can be used to help determine elemental abundances from nonelastic-scattering gamma rays, and the use of ground truths (as with the Apollo gamma ray spectra) or normalizing the sum of all abundances to unity may not needed. Similarly, direct measurements of the fluxes of thermal (and epithermal) neutrons can be used to determine abundances from fluxes of neutron-capture gamma rays. The elemental abundances derived from the gamma ray data are needed in interpreting the neutron measurements. The thermal/epithermal ratio can be used to get an independent measure of the effective $1/v$ macroscopic cross section for thermal neutrons. Differences of this macroscopic cross section determined from the major elements mapped with gamma rays from that inferred from low-energy neutrons could indicate the presence of other elements that strongly absorb thermal neutrons, such as Sm and Gd. Thus in many ways the complementary nature of gamma rays and neutrons make a combined gamma ray/neutron spectrometer more powerful than each technique by itself.

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References: [1] Lingenfelter R. E. et al. (1961) *JGR*, 66, 2665–2671. [2] Boynton W. V. et al. (1992) *JGR*, 97, in press. [3] Metzger A. E. and Drake D. M. (1991) *JGR*, 96, 449–460. [4] Bruckner J. et al. (1987) *Proc. LPSC 17th*, in *JGR*, 92, E603–E616. [5] Feldman W. C. et al. (1991) *GRL*, *18*, 2157–2160. [6] Moss C. E. et al., this volume. [7] Reedy R. C. et al. (1973) *JGR*, *78*, 5847–5866. [8] Reedy R. C. (1978) *Proc. LPSC 9th*, 2961–2984. [9] Evans L. G. et al. (1992) In *Remote Geochemical Analysis* (C. Pieters and P. J. Englert, eds.), Cambridge, in press. [10] Reedy R. C. and Arnold J. R. (1972) *JGR*, *77*, 537–555. [11] Reedy R. C. (1987) *Proc. LPSC 17th*, in *JGR*, 92, E697–E702. [12] Drake D. M. et al. (1988) *JGR*, 93, 6353–6368. [13] Lingenfelter R. E. et al. (1972) *EPSL*, *16*, 355–369. [14] Feldman W. C. et al. (1989) *JGR*, 94, 513–525.

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COMPAS: COMPOSITIONAL MINERALOGY WITH A PHOTOACOUSTIC SPECTROMETER. W. Hayden Smith, Washington University, St. Louis MO 63130, USA.

There is an important need for an *in situ* method of mineral and rock identification and quantification that provides true absorption spectra for a wide spectral range for lunar lander/rover missions.

Many common minerals, e.g., some feldspars, magnetite, ilmenite, and amorphous fine solids or glasses, can exhibit flat spectral reflectances in the 400–2500-nm spectral region that render inaccurate or difficult their spectral detection and quantitative analysis. Ideal rock and mineral spectra are, of course, pure absorption spectra that are independent of the spectral effects of scattering, particle size, and distribution that can result in a suppression or distortion of their spectral features. This ideal seldom pertains to real samples. Since sample preparation is difficult and may fundamentally alter the observed diffuse spectral reflectance, an *in situ* spectral measurement method for rocks and minerals on the Moon, insensitive to the sample morphology, would be invaluable.

Photoacoustic spectroscopy is a well-established technique appropriate for this task that has been widely applied in condensed-phase spectral studies of complex, highly light scattering, unprepared samples of everything from coal to whole blood, including rock and mineral characterization.

A Compositional Mineralogy Photoacoustic Spectrometer, or COMPAS, can enable *in situ* spectral measurement of rocks and minerals, bypassing the major limitations of diffuse reflectance spectroscopy. COMPAS has the following features: (1) it is designed for *in situ* spectral characterization of rocks and minerals and their surface weathering species; (2) it does not require modifying or altering the sample or its surroundings; (3) it provides spatial resolution on a submillimeter scale, functions at the ambient (high or low) temperature, and requires no coolants; (4) spatial and spectral data are acquired in a serial mode at a modest data rate; (5) it has no internal moving components, which gives it high reliability; and (6) it is physically very small with low weight and power requirements.