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ELEMENTAL MAPPING OF THE MOON USING GAMMA RAYS: PAST, PRESENT, AND FUTURE.

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Introduction: The energies and intensities of gamma rays from a planetary surface can be used to infer the elemental composition of an object with no or a thin atmosphere [1,2]. The Apollo gamma-ray spectrometers in 1972 and 1973 produced many of the results for the distribution of elements in the Moon that are now generally well accepted. Lunar Prospector in 1998 and 1999 globally mapped the Moon with gamma rays and neutrons. Both missions used spectrometers with poor energy resolution (~8-10%). The Japanese plan to send a high-resolution germanium gamma-ray spectrometer to the Moon in about 2004 on their SELENE mission. However, little has been done since the 1970s on the models used to unfold planetary gamma-ray spectra [1,2]. More work needs to be done on understanding what to expect in future gamma-ray spectra and how to unfold such data.

Past Gamma-Ray Results: The NaI(Tl) gamma-ray spectrometers on Apollos 15 and 16 showed that the lunar highlands were mainly anorthositic and that regions with high concentrations of naturally radioactivity were mainly in the western lunar front-side [3,4]. These Apollo data were used to map K, Th, Ti, and Fe over about 20% of the lunar surface [5] and yielded some Mg abundances [4].

The BGO gamma-ray spectrometer (GRS) on Lunar Prospector has extended Apollo-like results for Th, Ti, and Fe to the whole Moon [e.g., 6,7]. Work continues on analysis of the gamma-ray spectra measured by Lunar Prospector. One problem is that those spectra contain many unidentified background features that need to be better studied using data taken during the cruise to the Moon and other data [8].

Present Status: Work continues on the analysis of the Lunar Prospector data. Works also continues on better calculations to model the production of gamma rays in planetary surfaces. Monte Carlo codes are now used to calculate the particles made in an object by the cosmic rays, especially the secondary neutrons that make most gamma rays. These codes have been well tested with cosmogenic-nuclide data and yield results consistent with older gamma-ray calculations [9].

High-resolution spectrometers will result in many more gamma rays being detected. Good theoretical models will be needed to unfold such spectra. Very little has been done on the nuclear databases used for the production of planetary gamma rays since 1978 [2]. Improved energies and intensities for the gamma rays made by the capture of thermal neutrons have recently be evaluated for elements with Z=1-30 [10] and for several other elements of interest for planetary surfaces [11].

Very few experiments have been good simulations of the production of planetary gamma rays by cosmic rays. Several huge thick targets were irradiated with GeV protons and gamma-ray spectra were measured [12]. Preliminary comparisons of those spectra with calculations showed good agreement [13], although these thick-target results have not been well studied.

Future Work: The major emphasis now should be to complete work already in progress and to prepare for the analysis of the high-resolution gamma-ray expected from SELENE. In preparing for the Ge gamma-ray spectrometer that will go into Martian orbit in October 2001 on Mars Odyssey, much work is planned. The thick-target data will be examined in more detail to compare expected with measured gamma-ray spectra. One task will be to look for gamma rays that are broadened due to Doppler effects when the gamma ray is emitted from an excited level with a very short half-lives. Such broadening has been observed for the 4.438 MeV gamma ray made from excited carbon and is expected for other gamma rays.

New codes (MCNPX, GEANT) are or will be used to numerically simulate planetary gamma-ray production. Work needs to be done on getting the latest data for the gamma rays made by the decay of the natural radionuclides (such as ^{40}K and the U and Th decay chains). Cross sections as a function of energy are needed for gamma rays made by energetic particles, both for inelastic-scattering reactions used to map some elements (e.g., ^{24}Mg(n,nγ)^{24}Mg) and especially for interfering spallation reactions making the same gamma ray (e.g., ^{28}Si(n,nαγ)^{24}Mg).

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