X- and Gamma ray (10-200 keV) fluxes from various lunar terrain types for chemical mapping of the Moon.

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Key words: Gamma ray spectrometry, X-rays, Elemental distribution on Moon

Gamma ray spectroscopy is a useful technique for chemical mapping of planetary surfaces. Radiations produced from the decay of natural (e.g. U, Th, and K) and cosmogenic radionuclides (e.g. ^{22}Na, ^{26}Al, ^{153}Gd) as well as de-excitation of nuclei following their interaction with primary and secondary solar and galactic cosmic rays are characteristic of the concentration of the elements present on the Moon. Reedy [1] has estimated the fluxes of various lines for the energy region 0.2 to 10 MeV, assuming average lunar chemical composition. Gamma-ray spectra of the Moon have been measured during the Apollo missions by Arnold et al. [2] and more recently by Lawrence et al. [3] on Lunar Prospector for determining elemental distributions. Here, we extend the flux calculations to energy region below 200 keV, and discuss the possibility of measuring them with better spatial resolution.

We use an experimental approach based on the intensities of various lines in laboratory spectra of U and Th sources in which the series nuclides are in equilibrium. Using appropriate values for detector efficiency and attenuation coefficients, the fluxes of some lines of interest (Table 1) were calculated by normalizing a typical high energy flux to Reedy's value [1] for an orbiter at an altitude of 100 km. Several nuclides in decays chains contribute in the same energy regions as shown in Table 1 but it should be possible to isolate their contributions and determine U and Th distribution.

We have also calculated the fluxes of decay and de-excitation gamma rays from some Rare Earth Elements which have high neutron capture cross sections. Using appropriate isotopic abundances, photon yield per neutron captured, and attenuation coefficients, we estimated the fluxes for Gd, Sm, Nd and Eu isotopes, normalizing the high energy fluxes to the values estimated by [1].

Our results (Table 1) suggest that U, Th, Gd, and Sm can be measured in some lunar terrains. The most favourable case is that of KREEP, whereas the others (e.g. Highlands and Mare basalts) give lower intensities whose detection may be difficult. A 100 cm^2 collimated CZT detector with a CsI scintillator anticoincidence has been proposed for the Indian Moon Mission [4]. If the background due to spacecraft, Compton scattering and other sources can be minimized, it should be possible to map the lunar surface for some of these elements. The suite of elements which can be mapped using CZT is complementary to those measured by the accompanying X-ray fluorescence spectrometer. The latter is being designed to map Si, Al, Mg, and possibly Ca, Fe, Ti on the lunar surface. These two detectors together should provide distribution of several elements which are diagnostic of the early chemical evolution of the Moon.

References:

[1] Reedy, R. C. (1978), LPSC 9, 2961-2984. [2] Arnold, J. R., Metzger, A. E., and Reedy, R. C. (1978), LPSC 8, 945-948. [3] Lawrence et al. (1998) Science, 281 1484-1489. [4] Bhandari, N. Joseph, G. and Agrawal P.C. (2000) (Abstract) in Workshop on New Views of the Moon, Berlin, 14-16 January 2002.

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Table 1: X- and gamma ray fluxes* (photons s^{-1})

Element	Nuclides	Energy, keV	KREEP	High Al Mare basalts	Highland Crust
U	^{210}Pb	46.5	0.34	0.06	0.02
Th, U	^{228}Ra, ^{228}Th, ^{231}Th	84.2-84.4	0.58	0.12	0.05
Th, U	^{228}Ra,^{234}Th,^{228}Ac,^{231}Th	89.9-93.4	1.22	0.22	0.09
Th	^{228}Ac,^{228}Ra, ^{232}Th	129.1	0.40	0.08	0.04
U	^{226}Ra, ^{235}U	185.7-186.0	1.62	0.28	0.12
Gd	^{153}Gd	97.4	0.10	0.02	0.005
Gd	^{157}Gd (n, γ)	79.5, 181.9	0.10	0.02	0.005
Sm	^{153}Sm, ^{155}Sm	103.2-104.3	0.12	0.02	0.008

*Fluxes due to *in situ* production as seen by a detector with 100 cm^2 area at an altitude of 100 km from the lunar surface.