Complex correlation between chemical abundance and intensity of line gamma rays on the lunar surface

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Determining major and important trace elements in the lunar surface is essential in the lunar science. Gamma-ray spectroscopy is suited for measuring the elemental composition in the lunar surface. The Japanese lunar explorer SELENE will be launched in 2007, with high precision gamma-ray spectrometer to survey the chemical abundance of the whole surface of the Moon. The spectrometer employing a Ge detector for the first time in the lunar exploration is going to uniquely identify the major elements such as Fe, Mg, Ti, Al, Th, K, Ca, U, Si, O and possibly H.

The characteristic gamma rays from the lunar surface arise from both decay of long-lived radioactive nuclides and nuclear interactions of galactic cosmic ray (GCR) particles with surface materials of the Moon. Such interactions produce secondary neutrons, which lead to the emission of gamma rays, mainly from nonelastic scattering reactions with fast neutrons and neutron capture reactions with thermal neutrons. The energies of the gamma rays are indicative of the nuclides responsible for the emission, and the intensities are related to their concentrations. Therefore, production rates of line gamma rays and neutrons and transport process in the lunar surface should be investigated in detail. Assuming different abundances of the Apollo lunar soil samples and the average spectrum of galactic comic ray protons, energy spectra of lunar gamma rays and emission rates of line gamma-rays from major elements have been estimated by Monte Carlo simulation code Geant4.

Results clearly showed that the emission rate of gamma rays heavily depends on not only the chemical abundance but also neutron flux within the lunar subsurface. While the intensities of line gamma rays from Fe and Ti are mostly proportional to their elemental abundances, that from Al is found to decrease as its abundance increases. Such a complex correlation is attributed to change in neutron flux within the lunar subsurface and petrological restriction of elemental variation.

Line gamma rays used in this study are produced by inelastic scattering of fast neutrons. Production rate of fast neutrons in the lunar surface is roughly dominated by $A^{2/3}$, where A is the atomic mass of a nuclide. Therefore, when GCR particles are irradiated to the lunar surface where the compositions of heavy elements such as Fe and Ti are high, it is likely that the fast neutron flux becomes high as well compared to regions with abundant light elements such as Al. In lunar rocks, Al is mainly contained in plagioclase and Fe in olivine and pyroxene. Abundance of plagioclase and olivine/pyroxene usually has an inverse relationship in rock. That is, there is less Fe where there is more Al. Such a petrological restriction leads to complexity in which increasing amount of Al actually causes to decrease fast neutron flux because of the lack of Fe and Ti. Consequently, inelastic scattering gamma rays from Al decreases in spite of the increased abundance of Al.

The total emission rate of line gamma rays is found to be closely related to the change in neutron flux produced in the subsurface of the Moon. It is concluded that the concentration of heavy elements such as Fe and Ti among the major elements of the lunar surface material is directly indicative from the emission rate of their line gamma rays, while that of light elements such as Al should be determined with consideration of change in the abundance of heavier elements on the Moon. Therefore, while gamma-ray spectroscopy itself reveals important information regarding the chemical composition of the lunar surface, it is important that gamma-ray data be complimented by neutron spectroscopy data such as those expected by Lunar Reconnaissance Orbiter, or that careful and repeated computer simulations should be made for determination of elemental abundance with high reliability.