Monte Carlo simulation of neutron production and transport in the Moon: Effect of lunar subsurface water

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The intensity of thermal, epithermal, and fast neutrons emitted from a planetary surface provides information on the surface elemental composition, particularly on the hydrogen abundance. In an airless planetary surface, the galactic cosmic rays produce fast neutrons via nuclear interactions in the subsurface materials within a depth of tens centimeters. Then, the fast neutrons are moderated by interactions with subsurface materials including the secondary neutron production. This neutron transport process is terminated at the thermal neutron capture or the neutron leakage from surface. Because the hydrogen atom has a large elastic scattering cross section for a neutron and a nearly identical mass as a neutron, neutrons are efficiently moderated by the elastic scattering with hydrogen atoms. Therefore, the leakage neutron intensity strongly depends on the hydrogen abundance as well as the surface elemental composition. Neutron spectroscopy is thus well suited to detect subsurface water which may present at the lunar polar region. It is essential to obtain the abundance and distribution of lunar subsurface water from the viewpoint of planetary science and space resources for future manned activities.

In this study, the neutron production and transport in the Moon was modeled by Monte Carlo simulation with Geant4 10.3.p03. The effect of subsurface hydrogen abundance and spatial distribution was studied for in-situ water search in future lunar polar landing explorations. The leakage neutron intensity produced by protons and alpha particles in galactic cosmic rays was calculated for the lunar highland composition mixed with various amounts of hydrogen. The production depth and flux of subsurface neutrons, and the production depth of leakage thermal, epithermal, and fast neutrons were also calculated. It was confirmed that the leakage neutron intensity depends on the subsurface hydrogen abundance. The epithermal neutron intensity is particularly sensitive to the presence of subsurface hydrogen. Most of the leakage neutrons were produced within a depth of about 100 g/cm^2, which means that the neutron spectroscopy is mainly sensitive to the subsurface water in the top of surface with about 50 cm in depth depending on the surface density. When a dry layer presents at the top of surface, the leakage neutron intensity was found to depend on the dry layer thickness. The variation of leakage neutron intensity was detectable for the dry layer thickness less than about 80 g/cm^2. The behavior of lunar subsurface neutrons and its sensitivity for lunar subsurface water will be presented and discussed.

Keywords: Lunar water, Lunar polar region, Lunar landing exploration, Neutron spectroscopy, Galactic cosmic ray, Monte Carlo simulation

