Radiation Environment on the Lunar Surface estimated in Dose Equivalent

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Introduction: In the JAXA 2025 Vision for the next 20 years, JAXA would acquire technological capability to enable the extended human presence on the moon and to play a role as an equal partner in international projects. And Top science in the field of space science is promoted, while preparing for Japan's own human space activities and the utilization of the Moon. Therefore, research of radiation environment on the Moon is a prime task.

Radiation environment on the lunar surface is remarkably different from that of the Earth. The atmosphere of the Earth is so massive that galactic cosmic rays(GCRs) are shielded on the surface. The Moon, however, has no atmosphere and GCRs always pour on the lunar surface. GCRs interact with surface material and produce a number of secondary neutrons. Gamma rays are also emitted by inelastic scattering and capture reaction of secondary neutrons with surface material. When estimating space dose, it is important to discuss the contribution of not only GCR nuclear component but also secondary neutrons and gamma rays. Furthermore, nuclear composition such as Mg, Si, Fe, give a significant contribution on the dose, even though those fluences are very low, compared with that of proton.

Under the environment of the Earth, an ambient dose equivalent is used to estimate absorbed dose. ICRU sphere, or spherical object simulating human body, is used to calculate the dose. We calculated ambient dose equivalents for GCR nuclear component, secondary neutrons and gamma rays on the lunar surface.

Calculation: It is important to investigate the effect of galactic cosmic rays on tissue-equivalent plastics as a constraint on models of biological response to space radiation on the lunar surface. In case of GCR charged particles, absorbed dose is calculated from uniform flux of each particle and the stopping power for ICRU sphere(tissue equivalent material), and then ambient dose equivalent is calculated from the absorbed dose, by using quality factor corresponding to the weighting coefficient for each radiation.

In case of neutrons and gamma rays, the leakage intensities from the lunar surface are calculated by Monte Carlo simulation using Geant4 code. And we have adopted the conversion factor from the intensity to ambient dose equivalent which was reported by International Commission on Radiological Protection, ICRP. In the simulation, Apollo16 regolith sample is chosen as a typical material of lunar surface, and the averaged proton flux during the solar activity is irradiated to the surface material of the Moon.

Results and Discussion: The ambient dose equivalent of GCR nuclear component is estimated to be 99.0 mSv/year. The ambient dose equivalents of neutrons and gamma rays are 51.3 mSv/year and 2.5 mSv/year, respectively. It is found that neutrons greatly contribute to dose and more than half of total dose equivalent from GCRs are attributed to secondary neutrons. A majority of neutron dose are given by fast neutrons(more than 100 keV).

In case of GCR, energy deposition in target material increases with the square of charge number of incidence particles. Therefore, the doses from heavy particles in GCR over Ne were very important. In fact, the dose of heavy particles provided a significant portion of total dose. The dose obtained from Fe(30.6 mSv/year) especially was so large that it reaches about one third of the whole dose equivalent from GCR.

On the Earth, there is such a thick atmosphere that GCR don't arrive at the ground. Major radiations on the ground are secondary components of GCR, electrons muons and gamma rays. Total equivalent dose of only 1.6 mSv/year is given by a sum of those radiations on the Earth. It should be emphasized that a main source of radiation exposure is GCR directly pouring on lunar surface. As a result, total dose on human body is estimated to be 153 mSv/year on average. The value is found to be 100 times greater than that on the Earth.