PROCEEDINGS OF SCIENCE

Performance evaluation of the MoMoTarO detector as a moisture meter for lunar and ground operation

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Recently, lunar exploration has gained momentum internationally, as represented by the ARTEMIS Plan. We have developed a new compact neutron and gamma-ray radiation detector, the Moon Moisture Targeting Observatory (MoMoTarO), aiming to mount it on a future lunar rover to explore water resources in a contactless way. We have conducted lunar simulant experiments to simulate the exploration of water resources on the lunar surface and experiments simulating the investigation of soil compositions on the ground. We will report the latest results of these experiments in this poster.

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1. Introduction

Starting with the Artemis plan [1], space exploration is gaining momentum globally, and, in particular, the exploration of water resources on the Moon is attracting significant attention. Using lunar water as drinking water and hydrogen fuel, the Moon can serve as a base for long-term human space activities and as a starting point for missions to other planets such as Mars. Furthermore, studying the abundance and distribution of water resources in detail provides insights into planetary science, such as elucidating the origin of lunar water and the process of its migration and concentration.

Lunar water resources have been observed through various remote sensing techniques, including visible and near-infrared [2], far-ultraviolet reflectance [3], laser reflectance [4], and neutron spectroscopy [5][6]. These observations suggest the potential for abundant water resources in permanent shadow regions (PSRs), areas never exposed to sunlight, within pole craters on the Moon (Figure 1 left). Many of these observations have been made from lunar orbiting satellites, so high-resolution water resource distribution maps have not been created, and we cannot use lunar water as a resource. We have developed a new compact neutron and gamma-ray detector, Moon Moisture Targeting Observatory (MoMoTarO), aiming to mount it on a future lunar rover to explore water resources in a contactless way. We also aim to create water distribution maps with a spatial resolution of several meters and identify locations containing water resources exceeding 0.5 wt%.

1.1 Neutron spectroscopy on the Moon

Among the remote sensing technologies used for exploration of lunar water, neutron spectroscopy is sensitive to water located approximately 1 meter below the surface. This depth of sensitivity is due to the high penetration capability of neutron radiation, making it deeper than other remote sensing methods.

When galactic cosmic rays collide with surface materials on the Moon, nuclear reactions occur, and fast neutrons with high kinetic energy are produced. These fast neutrons efficiently lose their energy through collisions with light elements like hydrogen contained in water, becoming thermal and epithermal neutrons. It is possible to explore for water resources, by measuring different neutron energies leaking from the lunar surface and discriminating them by energy, and by measuring their rate coefficients(Figure 1 right).

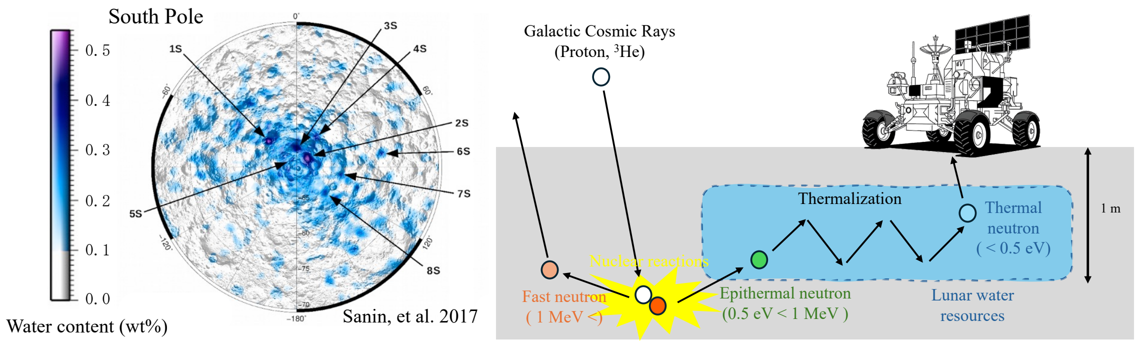

Figure 1: (Left)Water Distribution Map of the Lunar South Pole by the Lunar Reconnaissance Orbiter (LRO). (Right)Thermal and epi-thermal neutrons leaking from the lunar surface.

2. Moon Moisture Targeting Observatory (MoMoTarO)

The MoMoTarO detector employs a plastic scintillator (EJ-270) doped with ^{6}Li for neutron detection and silicon photo multipliers (SiPMs) for readout (Figure 2 left). With this new neutron detection technology, the MoMoTarO has realized a detector that is inexpensive, compact, low-power, and vibration-resistant compared to conventional neutron detectors using ^{3}He gas.Furthermore, the EJ-270 scintillation emission process differs when gamma rays, fast neutrons, or thermal/epithermal neutrons are injected. As a result, the time constant of the electrical signal induced by scintillation varies for each radiation particle type. Utilizing this property, the MoMoTarO employs a technique called Pulse Shape Discrimination (PSD) to distinguish between radiation types. PSD is defined as the ratio of the late-signal component to the total waveform charge, calculated as follows:

$$PSD = \frac{Q_{tail}}{Q_{total}} \tag{1}$$

Q_{total} represents the total charge of the output signal, while Q_{tail} indicates the charge of the signal's late component. Gamma-ray signals have a small PSD value due to their small late components, while neutron signals have a large PSD value due to their large late components(Figure 2 middle). By separating regions in the two-dimensional space of PSD and peak height, it is possible to measure the count rate while discriminating between thermal neutrons, fast neutrons, and gamma rays (Figure 2 right). However, there is still potential for improvement in the discrimination performance. Optimization of the analog circuit and enhancement of the digital processing will be conducted in the future.

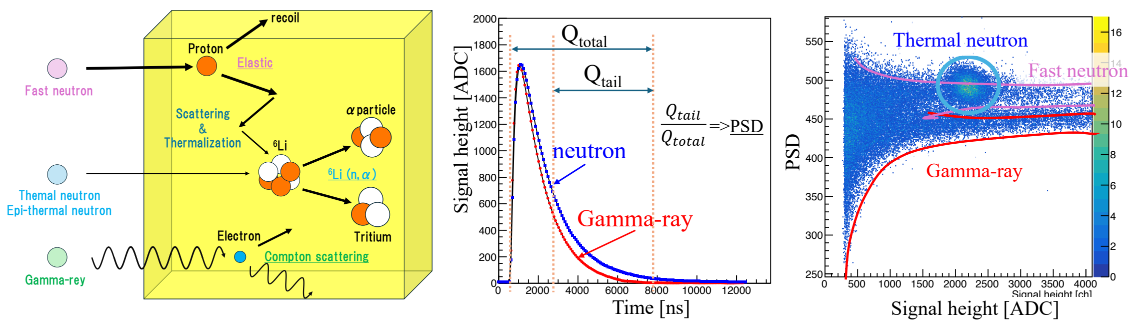

Figure 2: (Left)Interaction of thermal/epithermal neutrons, fast neutrons, and gamma rays with materials inside the plastic scintillator (EJ-270). (Middle)The signal induced by neutrons and the signal induced by gamma rays observed by the MoMoTarO. (Right)2D histogram observed by the MoMoTarO when irradiated with ^{252}Cf

3. Demonstration

3.1 The experiment with lunar simulant for lunar operation

Recent studies suggest that the water content of the lunar surface is at most 1.0 wt% or less [5]. To demonstrate the water resource exploration of the MoMoTarO under this extremely low-water-content lunar environment, a soil experiment was conducted using a lunar simulant (FJS-1). In this experiment, we prepared a homogeneous lunar simulant with a water content of 1 wt% or less and filled it into an aluminum soil container. Next, a Neutron source (^{252}Cf) was placed at the bottom of the soil tank, and the MoMoTarO was placed at the top. The leakage neutron rate from the top of the soil tank was measured for one hour while varying the water content of the lunar simulant to 0.1, 0.3, 0.7, 0.9, and 1.2 wt%. During measurements, environmental neutrons and recoil neutrons were shielded by enclosing the soil container and detector with B4C sheets (Figure 3).

The results show that the counting rate of thermal and epithermal neutrons increases with higher water content. This experiment shows that with this experimental setup, sufficient statistics can be obtained within a one-hour measurement time to distinguish between different moisture contents. We are planning experiments to simulate the installation of the MoMoTarO on a rover, running in a soil field, and to measure the spectral changes of leaked neutrons when the lunar simulant is divided into moist and dry layers.

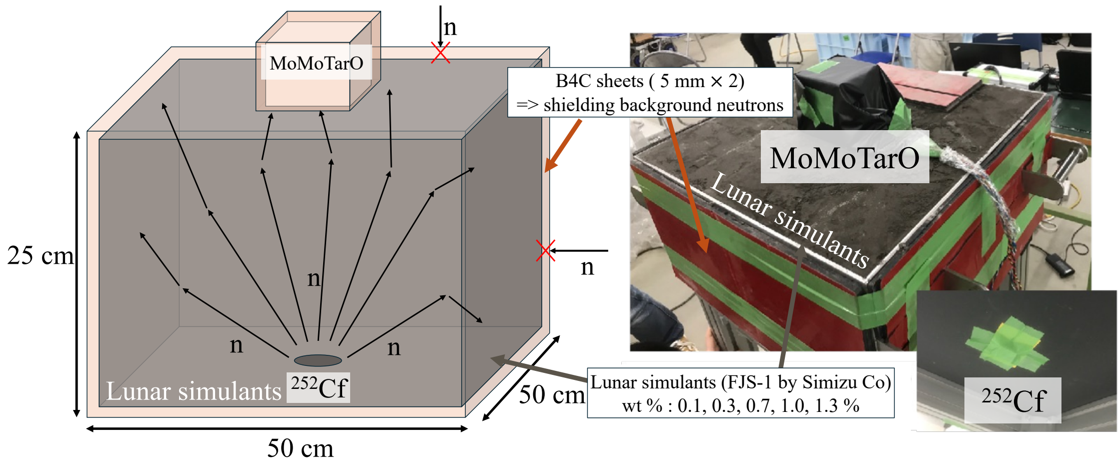

Figure 3: Schematic Diagram of lunar simulant expriment

3.2 The experiment with acrylic and glass board for ground operation

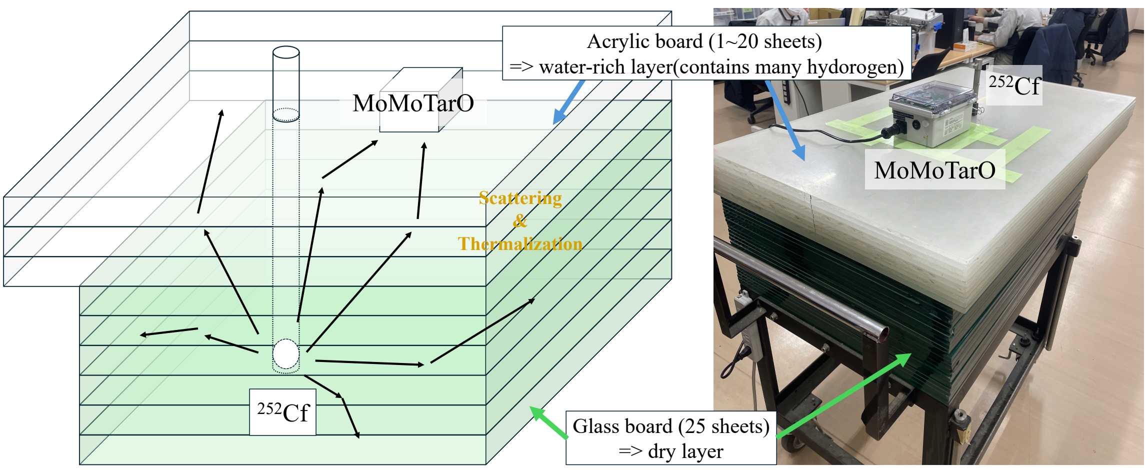

Figure 4: Schematic Diagram of the expriment with acrylic and glass for ground operation

Currently, soil moisture content measurements are primarily carried out using ^{3} He gas detectors, with a target soil moisture content ranging from approximately 0 to 80 wt%. Against the global increase in ^{3}He prices, MoMoTarO is expected to be an alternative to ^{3}He gas detectors. To compare the response of the MoMoTarO and ^{3}He gas detectors to thermal neutrons, experiments were conducted at a facility used for calibrating soil moisture measurements. In this experiment, we simulated moist soil using acrylic plates rich in hydrogen (simulating a water-bearing layer) and glass plates devoid of hydrogen (simulating dry soil). The experimental setup consisted of acrylic plates(several plates) layered on top of glass plates (25 plates), with a ^{252}Cf source rod inserted into a hole drilled at the center. We measured gamma rays and neutrons leaking from the surface using the MoMoTarO and ^{3}He detectors. By varying the number of acrylic plates incrementally from 0 to 20, we simulated a range of water content from 0 to 80 wt%.

Figure 5 shows the results for the number of thermal neutrons, gamma rays, and fast neutrons detected depending on the number of acrylic plates by the MoMoTarO. The results show that up to 5 plates, the number of thermal neutrons detected increases due to neutron thermalization, while beyond that number, it decreases due to thermal neutron absorption reactions. This trend was similarly observed with both the MoMoTarO and ^{3}He gas detectors, suggesting that the MoMoTarO can be applied to moisture content measurement using the same principle as the ^{3}He gas detector. Furthermore, since the MoMoTarO is also sensitive to gamma rays and fast neutrons, it is suggested that measurements of gamma rays and fast neutrons could potentially improve the accuracy of moisture content measurement and enable the measurement of soil density.

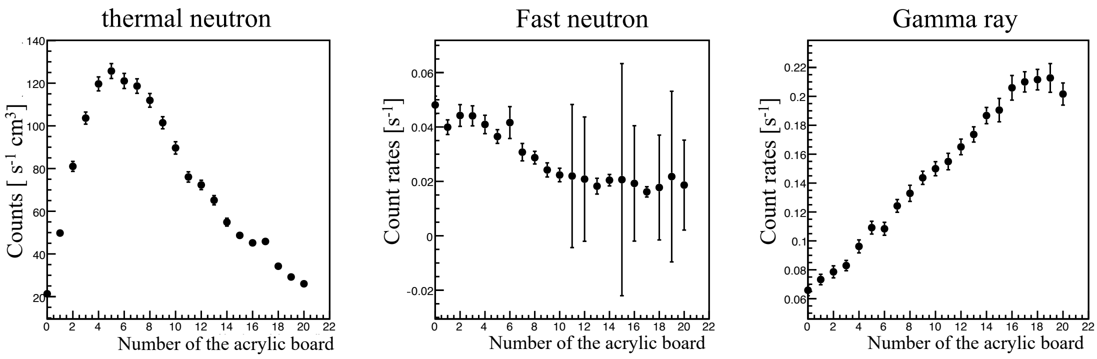

Figure 5: (Left) The number of thermal neutron detections depending on the number of the acrylic plates. (Middle) The number of fast neutrons detections (350 keVee≤) depending on the number of the acrylic plates. (Right) The number of gamma rays detections(350 keV≤) depending on the number of the acrylic plates.

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