NEUTRON COUNTING FOR WATER DETECTION ON PLANETARY BODIES: DEVELOPMENT OF THE FLIGHT-READY RANCH INSTRUMENT AND A MEASUREMENT TECHNIQUE. Y. Shimizu[1,2], H. Miyamoto[1,2], T. Takemoto[1,2], M. Kobayashi[1,2], T. Ikenaga[3], K. Kashiwagi[3], Y. Mitsuya[4], Y. Isobe[1,2], A. Preat[1,2], Y. Takahashi[4]. [1]School of Engineering, Department of Systems Innovation, Univ. of Tokyo, Tokyo, 113-8656, Japan (shimizu@seed.um.u-tokyo.ac.jp). [2]Center for Space Resources and Innovation, Univ. of Tokyo, Tokyo, 113-8656, Japan. [3]Soil and Rock Engineering Co. Ltd., Osaka, 561-0834, Japan. [4]School of Engineering, Department of Nuclear Engineering and Management, Univ. of Tokyo, Tokyo, 113-8656, Japan.

Introduction: Detection and mapping of hydrogen on planetary bodies provide important insights into the distribution of water and volatile materials in the solar system and play a key role in future space resource utilization. Because hydrogen efficiently moderates fast neutrons to epithermal/thermal neutrons, variations in neutron energy flux can be used to infer hydrogen abundance in planetary regolith, which is commonly associated with water or water ice.

On the Moon, Lunar Prospector (LP) and the Lunar Exploration Neutron Detector (LEND) revealed enhanced hydrogen concentrations near the poles, particularly in permanently shadowed regions [1, 2]. Similar techniques have also been applied to Mars, where neutron measurements from the Mars Odyssey mission detected strong hydrogen enrichment at high latitudes interpreted as subsurface water ice [3]. In addition, the Dynamic Albedo of Neutrons (DAN) instrument onboard the Mars Science Laboratory rover demonstrated that active neutron measurements can probe hydrogen within the shallow Martian subsurface during rover operations [4].

However, most hydrogen measurements so far have been passive measurements and obtained by orbiters, which limits spatial resolution and makes it difficult to constrain the local abundance and distribution of hydrogen within the regolith. Although DAN successfully demonstrated active neutron measurements on the Martian surface, the vertical distribution of hydrogen remains poorly constrained over wide regions. Thus, in-situ measurements capable of probing hydrogen directly at planetary surfaces are highly desirable for future landers, rovers, and sample collecting missions.

Hydrated minerals and water-bearing materials have also been identified on several asteroids through remote sensing observations and sample return missions, but direct measurements of hydrogen on asteroid surfaces remain extremely limited.

To address this need, we develop the Regolith Active Neutron Counter for Hydrogen (RANCH), a compact neutron counting instrument. A flight model has already been completed for a mission scheduled for launch in 2027. In addition, we propose a novel and simple measurement technique using the active neutron source to estimate the concentration and distribution of subsurface water on planetary bodies. Both the RANCH instrument and this measurement technique provide a practical approach for identifying water on planetary bodies, which is essential for future space resource utilization.

RANCH instrument: RANCH incorporates compact sealed radioactive sources similar to those used in industrial measurement devices such as moisture meters and smoke detectors. The neutron source unit has dimensions of 20 mm × 20 mm × 8 mm, and hydrogen detection is performed using a compact scintillator (160 mm × 50 mm × 10 mm). The instrument includes electronics that process neutron signals, classify events by energy, and store measurement data before transmission to the spacecraft or rover computer.

RANCH also includes a gamma-ray source that enables bulk density measurements of the surrounding regolith through attenuation and scattering processes such as Compton scattering.

The total mass of RANCH is approximately 300 g and the electrical power consumption is about 0.5 W. A flight model of the instrument has been completed (Fig. 1).

Laboratory experiment and numerical validation: Laboratory experiments are conducted using the RANCH instrument to evaluate its capability for determining the water content of regolith samples. Simulated lunar and asteroid regolith materials are prepared and measured under two configurations: measurements of collected samples and measurements of surface materials in situ. The water content of the samples is varied from 0.0 to 10.0 wt%, and each measurement is conducted for 10 minutes.

Fig. 1 shows the neutron counting results. The detected neutron counts increase with increasing water content. The counts are well fitted by an exponential function (R^2 = 0.999), indicating a strong correlation between neutron counts and water content and demonstrating that the water content can be estimated with high precision.

Monte Carlo simulations are also performed using the same experimental configuration. We show that the numerical simulation reproduce the trends observed in the laboratory measurements, confirming the validity of the measurement principle.

Active Neutron Counting with Variable Source–Detector Distance: If we use an active neutron source, its measurement geometry can be flexibly controlled. We therefore develop a novel measurement technique to estimate the depth profile and distribution of subsurface water ice more precisely compared to the conventional passive measurements [5].

In this method, the scintillator remains fixed while the neutron source is moved to vary the source–detector distance (Fig. 2). By analyzing neutron count rates as a function of this distance, the depth and abundance (wt%) of subsurface water ice can be inferred simultaneously.

Fig. 2 shows the results of Monte Carlo simulations of this measurement concept for a lunar surface environment with a buried icy regolith layer. The simulations show that the neutron count rate decreases differently depending on the depth and abundance of the buried ice. Subsurface layers containing water ice can be distinguished when located at depths shallower than approximately 60 cm [5].

These results suggest that this method provides a practical approach for investigating subsurface water on planetary surfaces and is well suited to compact surface instruments such as RANCH.

Summary: We have developed RANCH, a compact, lightweight, and low-power active neutron counting instrument capable of estimating the water content (wt%) of planetary surface and subsurface regolith. The flight model of RANCH has already been completed, enabling its use in upcoming exploration missions. We also established a novel measurement technique based on active neutron counting with variable source–detector distance, which enables improved estimation of the depth and abundance of subsurface water ice.

RANCH offers high flexibility for spacecraft and rover integration. Because of its compact size and light weight, the instrument can be mounted at various locations on spacecraft or rover platforms. Measurement sensitivity can also be optimized by adjusting the instrument placement or measurement duration.

Researchers and mission teams interested in RANCH are welcome to contact the authors. We would be happy to discuss potential opportunities to include this payload in future exploration missions. Note that the radioactive sources used in RANCH are small sealed sources similar to those used in industrial instruments and present minimal risk for spacecraft or rover integration. Launch requirements have already been discussed with launch providers.

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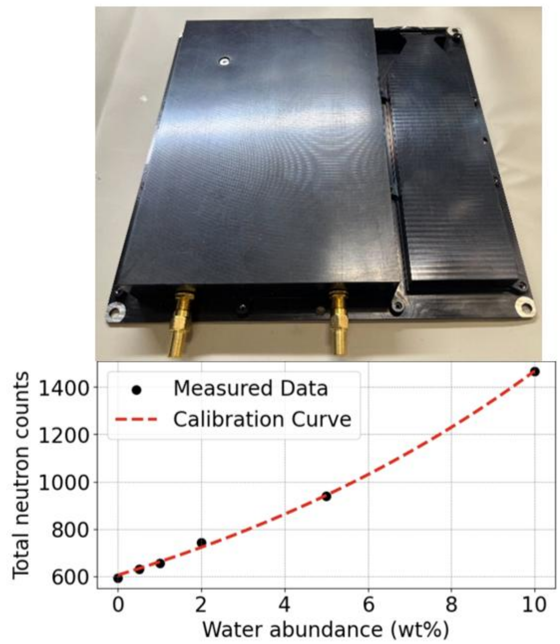

Fig. 1. (Upper) RANCH flight model. (Lower) Laboratory measurement results.

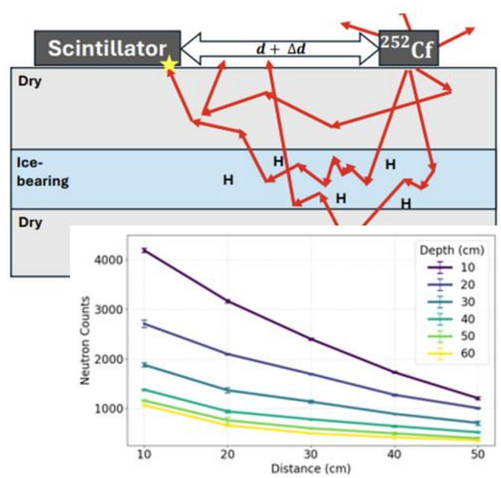

Fig. 2. (Upper) Schematic of the measurement technique. (Lower) Results of numerical simulations.