LUNAR GEOCHEMISTRY AND PROSPECTING WITH THE KPLO GAMMA-RAY SPECTROMETER.

N. Yamashita[1], T. H. Prettyman[1], [1]Planetary Science Institute, Tucson, AZ (yamashita @ psi.edu).

Introduction: The elemental compositions of the lunar surface enable us to investigate lunar geology, guide landed missions, and support future resource utilization [e.g., 1,2]. The knowledge of how volatiles are transferred on the lunar surface gives insight to the surface outgassing and the thermal conditions of the regolith, and the dynamics of the exchange of gases between the regolith and the exosphere.

To broaden our knowledge of the Moon through elemental analyses, we aim to analyze and derive elemental maps of the Moon using nuclear spectrometry data to be acquired by the Korea Pathfinder Lunar Orbiter (KPLO) Gamma-Ray Spectrometer (GRS) [3]. The target elements include the major rock-forming elements O, Mg, Al, Si, Ca, Ti, and Fe, radioelements K, Th, and U, the volatile element radon (Rn), and rare earth elements Sm and Gd. We also seek to determine the abundance of hydrogen (H) in the permanently shadowed regions at the poles, contingent on the instrument's capability.

Mission and Instruments: The KPLO is scheduled for launch by a SpaceX Falcon 9 in August 2022. Its primary mission will be conducted in the circular lunar polar orbit at the altitude of ~100 km with an inclination of ~90° for 11 months.

The KPLO carries a GRS which employed a $LaBr_3$ scintillator as the main detector. The GRS has a very broad energy range starting from 30 keV, in contrast to prior missions of ~200 keV with Kaguya GRS and ~500 keV with Lunar Prospector (LP) GRS [5,6]. KPLO's unique and unprecedented energy range and expected energy resolution (~ 4% full-width-at-half-maximum at 662 keV) will enable us measure Rn, U, and rare earth elements.

Surrounding the main detector is a shielding detector composed of boron-loaded plastic (BLP) scintillators (Fig. 1). While the BLP serves as a coincidence and anti-coincidence shield against cosmic rays, it is also capable of detecting neutrons. The variations in the neutron flux have been used to and determine the H abundances on planetary surfaces [7-11].

Elemental Investigations: Using the KPLO GRS data, we seek to determine the abundance and distribution of more elements than those previously studied, enabling further investigation of volatiles and resources. In cooperation with Korea Aerospace Research Institute and the KPLO team, we help plan an observation strategy and develop a data reduction and analysis pipeline prior to launch. This will contribute to timely data reduction and production of higher-level data products. Some of our research focuses are described below:

Fig. 1 Drawing of KPLO GRS sensors. Adapted from [3].

Outgassing and Transport of volatiles. We will use progenies of radon (^{222}Rn) as a proxy for volatiles to study their outgassing and dispersion on the lunar surface in non-polar regions. Radon, the only volatile and gaseous element in the uranium series, can escape from the lunar regolith and spread out over the lunar surface. Apollo, Kaguya, and Lunar Prospector alpha-particle spectrometers measured increased Rn abundances specifically over the Aristarchus region, which suggests the Moon may still be geologically active [12-14].

We will employ the following gamma rays with energies characteristic to the decay stages in the uranium series. To determine the original distribution of uranium, the source of Rn, we will measure the intensity of the 92 keV gamma-ray doublet emitted when ^{224}Th, a daughter nuclide of ^{238}U, decays. As an indicator for the transport of Rn, we will use two gamma rays, 46.5 keV and 352 keV, to assess dispersion at different time scales. We will also compare the result with the global map of U observed by Kaguya GRS [6]. We will determine if allowances are needed in order to extrapolate from Rn behavior to that of lighter lunar volatiles (especially H) [15]. Such measurements would provide a precursor study for the landing site selection for the in-situ alpha-ray observation of Rn by the French DOWN instrument [16,17] onboard Chang'E-6 in 2023.

Direct identification of Sm and Gd. We will explore and uniquely determine the distribution of rare earth elements with low-energy gamma rays. Among many of them, we focus on Sm and Gd, which have very high neutron capture cross sections (Table 1). The proposed ability to map Sm and Gd separately from Th could add novel and important information about variations within the Procellarum KREEP Terrane, constraining the very last stage of crustal formation [1,18]. We have identified some of the characteristic gamma-ray lines that are potentially useful for this purpose. Leakage currents in Table 1 were calculated assuming the elemental abundances of the Apollo 14 landing site [2] and prorating the values reported in [19].

Table 1 Low-energy lunar gamma rays emitted from rare earth elements (Sm and Gd). Emission cross sections due to the radiative capture of thermal neutrons are denoted as σ_γ [4].

Nuclide	Energy (keV)	σ_γ (barns)	Leakage current (γ/cm^2/min)†
^{157}Gd(n,γ)	79.5	4010	1.05
^{157}Gd(n,γ)	89.0	1380	0.32
^{157}Gd(n,γ)	181.9	7200	1.10
^{157}Gd(n,γ)	199.2	2020	0.30
^{149}Sm(n,γ)	334.0	4790	1.80
^{149}Sm(n,γ)	439.4	2860	1.25

Search for hydrogen at poles using the shield detector. Epithermal and fast neutrons are sensitive to the existence of hydrogen [e.g., 20]. Hydrogen is a promising resource on the Moon and improvement in our knowledge of its distribution will greatly help future landed missions [21,22]. Quantitative assessment of sensitivity of the GRS to hydrogen requires the detailed information on detector geometry and specification. We will work with the KPLO GRS team to evaluate the sensitivity of the BLP to the H abundances for simultaneous observations with gamma rays.

Modeling and Validation. We will model the leakage current of gamma rays from the Moon, the detector response for quantitative interpretation of gamma-ray count rates, and spacecraft ephemeris and pointing for thorough elemental investigations. Once we obtain elemental maps, we will validate our results with elemental and mineral datasets reported by prior missions, including LP and Kaguya [5,6,23,24].

Data archiving: We will archive the results from the KPLO GRS data in the PDS4 format at PDS-compliant repositories (NASA Planetary Data System and/or Korea Aerospace Research Institute Planetary Data System), ensuring that the data are promptly available to the lunar community for scientific research and planning. We will develop and archive high-level data products, including fully corrected and calibrated time-series spectra and maps of characteristic gamma rays and derived elemental abundances. The pixel sizes for the maps will depend on the observation time, background count rates, and GCR intensities.

Acknowledgement: Portions of this material are based upon work supported by the NASA under Grant No. 80NSSC 21K0712 issued through the Korea Pathfinder Lunar Orbiter Participating Scientist Program.

References: [1] Jolliff, B.L., et al. (2000) *JGR*, 105, 4197-4216. [2] Lucey, P.G., et al., (2006) in *New Views of the Moon*, p. 83-219. [3] https://cosparhq.cnes.fr/assets/uploads/2021/01/South-Korea_2020_compressed.pdf. [4] Firestone, R.B., *Table of Isotopes 8th edition*. 1999. [5] Prettyman, T.H., et al. (2006) *JGR*, 111. [6] Yamashita, N., et al. (2010) *GRL*, 37, L10201. [7] Lawrence, D.J., et al. (2015) *Icarus*, 255, 127-134. [8] Lawrence, D.J., et al. (2013) *Science*, 339, 292-296. [9] Prettyman, T.H., et al. (2012) *Science*, 338, 242-6. [10] Prettyman, T.H., et al. (2017) *Science*, 355, 55-59. [11] Boynton, W.V., et al. (2002) *Science*, 297, 81-85. [12] Gorenstein, P., et al. (1974) *Science*, 183, 411-413. [13] Lawson, S.L., et al. (2005) *JGR*, 110, E09009. [14] Kinoshita, K., et al. (2016) *LPS*, 47, Abst. #3070. [15] Hodges, R.R., et al. (1974) *Icarus*, 21, 415-426. [16] https://presse.cnes.fr/sites/default/files/drupal/201911/default/cp156-2019_-_chine_va.pdf. [17] Meslin, P.Y., et al. (2020) *LPS*, 51, Abst. #1741. [18] Elphic, R.C., et al. (2000) *JGR*, 105, 20333-20345. [19] Reedy, R.C. (1978) *Proc. Lunar Planet. Sci. Conf., 9th*, 2961-2984. [20] Feldman, W.C., et al. (1998) *Science*, 281, 1496-1500. [21] Crawford, I.A. (2015) *Prog. Phys. Geograph.*, 39, 137-167. [22] Inoue, H., et al. (2019) *LPS*, 50, Abst. #2155. [23] Yamashita, N., et al. (2012) *EPSL*, 353-354, 93-98. [24] Naito, M., et al. (2018) *Icarus*, 310, 21-31.