IDENTIFICATION OF VOLATILE ELEMENTS FOR LUNAR SCIENCE, RESOURCE UTILIZATION, AND LANDING SITE SELECTION. N. Yamashita[1] and T. H. Prettyman[1], [1]Planetary Science Institute, Tucson, AZ 85719 (yamashita @ psi.edu).

Introduction: We seek to improve our knowledge of elemental abundances on the Moon using the Kaguya/SELENE Gamma-Ray Spectrometer (KGRS) data. Better characterization of subsurface geochemistry will contribute to lunar science, resource utilization, and landing site selection for future human and robotic exploration.

The Moon is a convenient laboratory for understanding processes underlying planetary formation and evolution. The surface of the Moon preserves a record of geochemical processes that occurred primarily during the past 3–4 billion years [1,2]. Many landed lunar missions are being proposed, leveraging recent advances in space technology [e.g., 3-5]. In addition, evidence for ice in permanently shadowed craters has led to interest in using the Moon as a refueling base for human exploration of the solar system [e.g., 6,7].

The elemental composition of the lunar surface provides crucial information needed to understand lunar formation and evolution as well as to identify and extract resources. JAXA's KGRS employed a high energy resolution HPGe to determine subsurface elemental composition [8,9]. This data set will complement high-efficiency gamma-ray spectroscopy data acquired by Lunar Prospector (LP) and planned for the Korea Pathfinder Lunar Orbiter (KPLO) [10,11].

Data Set: The calibrated gamma-ray spectra acquired by the KGRS are available for public at NASA's Planetary Data System (PDS) Geosciences node, together with ephemerides, geometry correction factors, and documentation [12-14]. We will spatially and/or temporally accumulate the time-series spectra to search for spectral signatures of elements of interest. Many of elemental signatures in spectra are interfered by closely clustered gamma-ray peaks. Therefore, sufficient spectrum (energy) resolution is essential to uniquely and precisely retrieve additional elemental information. The KGRS had an energy resolution of 4 keV (full width at half maximum at 662 keV), while the LP-GRS had that of 80 keV [8,9,11].

Elemental Investigations: We are using the KGRS data to determine the abundance and distribution of more elements than those previously studied, enabling further investigation of minerals and volatiles. Our research focuses on the following investigations:

Outgassing and Transport of volatiles. Transport and dispersion of volatiles in non-polar regions of the Moon can be characterized using progenies of radon (^{222}Rn) as a proxy for other volatile species such as water molecules. Radon is produced by the spontaneous decay in the uranium series which begins with naturally occurring ^{238}U within the outer crust. Radon is gaseous and the half-life of ^{222}Rn is 3.8 days allowing it to escape and disperse over the lunar surface. The study of Rn emanation was first suggested by [15]. Apollo, Kaguya and LP alpha-ray spectrometers measured increased Rn abundances specifically over the Aristarchus region, which suggests the Moon may still be geologically active [16-18]. Light lunar volatiles (H, He, and Ne) behave differently from heavier gases (Ar) that condense onto the lunar surface at night [19]. Radon should behave more like Ar than the light gases, at least within the exosphere [19]. We will determine if allowances are needed in order to extrapolate from Rn behavior to that of lighter lunar volatiles (especially H). For better characterization of Rn daughter products, it would be ideal to additionally measure very low-energy (40–100 keV) gamma rays, as proposed by the Chandrayaan-1 and KPLO missions [10,20]. Even though the threshold energies of KGRS and LP-GRS were ~140 keV and ~500 keV, respectively, the KGRS data would provide a precursor study for the future low-energy gamma-ray observation from the orbit by KPLO-GRS, and for the landing site selection for the in-situ alpha-ray observation of Rn by the French DOWN instrument [21,22] onboard Chang'E-6 in 2023.

Better characterization of highland plagioclase feldspar series. Sodium (Na) is a moderately volatile lithophile element found to be depleted on the surface of the Moon, Mars, and Vesta [23]. The lack of Na (and K) is responsible for a much higher anorthite content on the Moon than that that typically found in plagioclase in terrestrial rocks [2]. However, the existence of a Na-rich crust was inferred by X-ray observations of the Moon and by gamma-ray observations of Mercury [24,25]. That would require a complex evolution mechanism such as serial magmatism [e.g., 26] rather than the simple magma ocean to form today's feldspathic crust [27]. This would force us to change our current understanding of the crustal formation. The lack of Na on the Moon is typically explained by the Giant Impact Theory, in which the volatiles are lost in high temperature processes. Therefore, the bulk abundance of Na on the Moon can impose restrictions on temperature of formation and loss mechanisms.

Unambiguous detection of hydrogen. The H gamma-ray peak at 2.223 MeV can be used for unambiguous detection of hydrogen in the subsurface. It will further constrain the lateral and vertical

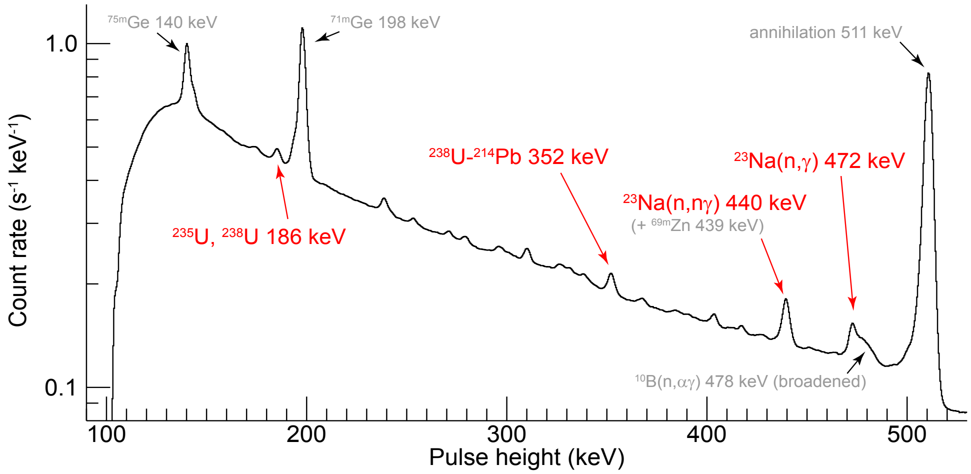

Fig. 1 Globally-averaged gamma-ray spectrum below ~500 keV acquired by the Kaguya GRS. Some of the gamma-ray peaks of interest for this study are shown in red, along with the major background sources identified in gray.

distribution of the volatile. H is essential to understand the delivery and storage mechanism of the exogenic highly-volatile species on planets, not only at the poles but also in equatorial regions [28-33]. H is also considered a potential resource, useful as a rocket fuel and a reducing agent [e.g., 6,7]. Unambiguous detection of H will help plan scientific aspects of future missions that explore the lunar polar region (e.g., LunaH-Map [34], VIPER [3], SELENE-R [5], and Artemis) as well as planetary protection aspects [e.g., 35].

Results: Preliminary results of these investigations will be presented at the conference. We identified several gamma-ray peaks that are indicative of the elemental abundances of the lunar Rn and Na (Fig. 1). The 186-keV gamma ray is emitted by the ancestor of Rn, and the 352-keV by the progeny of Rn in the uranium series. The distribution of the two gamma rays would differ if there was transport of gaseous Rn. The Na gamma rays induced by both low- and high-energy neutrons were also identified (Fig. 1). The distribution of subsurface water ice was explored using the H gamma rays observed in the lowest orbits (10–35 km) [36]. In this preliminary analysis, the interferences from the nearby peaks in the spectrum were removed by the peak fitting method. Only limited corrections were applied to the H map so far. The general trend of the oblique distribution of the counts around the south pole was obtained, which is consistent with prior studies. However, we also see anomalously high counts between 210° and 270°E at ~75°S where ice is not expected at depths sensed by the spectrometer. Further study of these regions, spectra, and observation conditions are needed to ensure accurate mapping of the lunar poles.

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