SNFLER: Surface Neutron Flux with Lunar Empirical Ratio Tim Livengood[1,2], Gordon Chin[2], Charles Clark[1,3], Michael Coplan[1], Tim McClanahan[2], Ann Parsons[2]. [1]University of Maryland, timothy.a.livengood@nasa.gov; [2]NASA Goddard Space Flight Center; [3]National Institute of Standards and Technology.

Introduction: The Surface Neutron Flux with Lunar Empirical Ratio (**SNFLER**) instrument is a surface-deployed neutron flux sensor to "**sniff out**" hydrogen in the regolith, presumed to be (mostly) in the form of water. SNFLER will operate at human-traversable scales or from a fixed location to establish ground truth for inferred hydrogen, presumed to be as water, in comparison to orbital mapping and collected samples. Orbital measurements of suppression in the natural leakage flux of epithermal neutrons have mapped hydrogen content in the near-surface regolith, with some ambiguities and challenges to calibration [1–3]. At the surface, with zero velocity and near-fixed altitude above the regolith, a new analysis mode becomes available in which hydrogen suppresses epithermal neutron flux and promotes thermal neutron flux. The flux ratio is a dimensionless measure proportional to the hydrogen content that compensates for confounding effects from variable cosmic ray flux (the source of lunar neutrons) and from temperature effects on neutron scattering cross-section.

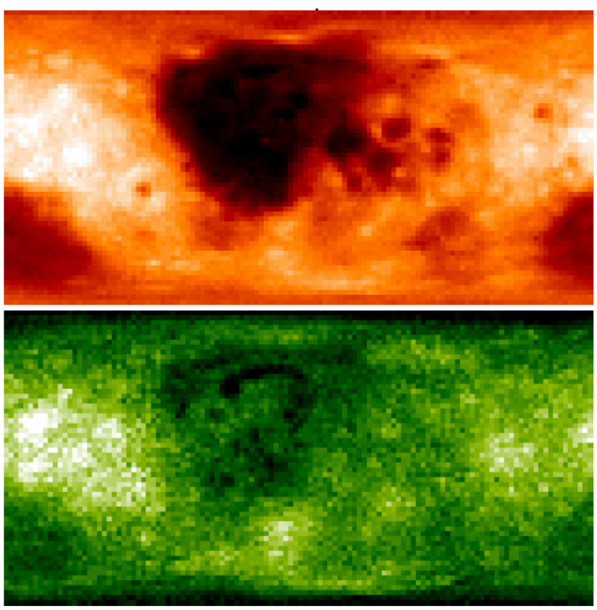

Fig. 1: Neutrons are emitted globally across the Moon in thermal (top) and epithermal (bottom) energy range. The relative flux of neutrons in each energy range is affected by geochemistry. In a limited region, such as the area accessible to an astronaut on EVA, geochemistry is roughly uniform and the dominant influence will be local variations of hydrogenation [4].

Related work: Neutron instruments using ^{3}He proportional counters have previously flown to lunar orbit to measure water in the polar regions and to map the global distribution of neutron leakage flux [4-6] (Fig. 1), including the Lunar Exploration Neutron Detector (LEND) on the Lunar Reconnaissance Orbiter (LRO) and the Lunar Prospector (LP) neutron spectrometer. The LunaH-Map smallsat mission is in preparation to capture improved spatial resolution maps of the South Pole specifically [7], and the VIPER rover mission is anticipated to carry a neutron instrument. LunaH-map is the only one of these instruments to use a detection technology other than the ^{3}He-based counter.

Abundance and location of water near the poles: The spatial average abundance of hydrogen determined from LEND poleward of 80° latitude, measured as water-equivalent hydrogen (WEH) is about 0.11% by weight, increasing to about 0.13 wt% WEH near the poles [4]. Deposits of water had been expected to reside within permanently shadowed regions (PSRs) and be relatively desiccated elsewhere [8], but measurements with the LEND collimated neutron detector have not supported this conclusion and do not agree with a sharp distinction between the large PSRs and neighboring regions [1]. Illumination differences at similar latitude are correlated with distinctions of neutron flux suppression, implying differences in hydrogenation between pole-facing and equator-facing sloped surfaces [2]. This reinforces the surprise that there is not more disparity between regions that are illuminated compared to those that are completely unilluminated.

Recent work to consider the spatial distribution of small-scale PSRs and temporarily shadowed regions suggests a possible reconciliation to explain the apparent broad distribution of trapped polar hydrogen outside of large PSRs [9]. This concept invokes numerous small-scale and relatively dense patches at the meter-scale, separated by dry regolith, all falling well below the resolution of orbital neutron instruments. SNFLER would sniff out these hydrogenated patches at the ground level. The actual distribution of water deposits, their size, and the abundance of trapped water are critical factors to consider for in situ resource utilization (ISRU). SNFLER could support robotic or astronaut exploration sorties to probe the location of water deposits.

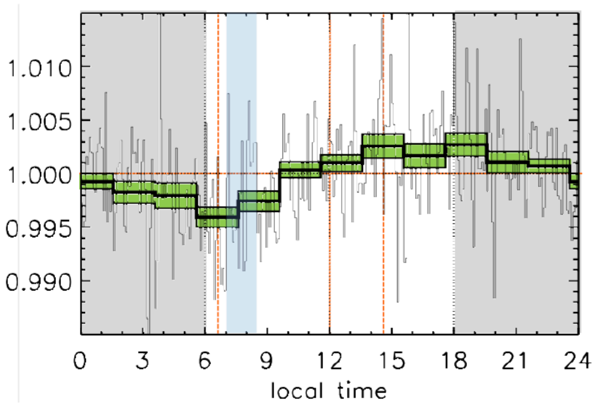

Fig. 2: SNFLER can measure diurnal variability of subsurface hydrogen on the Moon with improved SNR and local time resolution. The diurnal variation of epithermal neutron flux observed at low latitude from orbit by LEND [10] shows a variation consistent with a pile-up of water near the dawn terminator. SNFLER may use similar detectors on the lunar surface at a fixed location to achieve similar SNR in half the local-time step and automatically compensate for systematic effects to achieve a definitive measurement of subsurface hydrogen variation with time.

Abundance and mobility of water away from the poles: LEND data have been used to investigate the diurnal variation in subsurface water at low latitude, with surprising results [10] (Fig. 2). The diurnal pattern of suppression in epithermal neutron flux near the equator appears to confirm a local maximum of hydrogen/water near the dawn terminator, consistent with horizontal transport of water over the surface. The abundance of vapor-phase water implied by this mobility exceeds a surface-bounded exosphere in the Moon's morning period [9], in stark contrast to the current understanding of the lunar atmosphere. A fixed-station deployment of SNFLER early in the lunar day and lasting to dusk would enable a definitive measurement of how much hydrogen is in the subsurface regolith. SNFLER could determine whether hydrogen/water actually is transported horizontally or instead has been mimicked by another process such as thermal modulation of neutron cross-section, an effect to which the flux ratio is less sensitive than the direct measurement in each energy range.

Measurement goals and deployment: The detectors currently in use with LEND achieve a count rate of about 10 cps epithermal, about 20 cps for thermal neutrons. Surface count rate would be greater, but conservatively, the current LEND count rate can be used to estimate performance. The modulation shown in Fig. 2 corresponds to 0.013±0.002 wt% WEH at equatorial dawn, a factor of 8.5 less than the average polar region concentration. Similar signal-to-noise ratio on the equatorial hydrogen abundance could be achieved by SNFLER at the surface in a little more than one Earth day, enabling the modulation to be sampled about twice the sampling rate shown in Fig. 2. The neutron flux suppression due to the average polar region abundance could be measured to this SNR within 20 minutes. If the distribution of water consists of hydrogenated patches surrounded by dry patches of about ten times the surface area, then the hydrogenated/hydrated patches can be distinguished in well under a minute of signal integration. SNFLER thus can be an effective exploration tool in the hands of an astronaut, and an important geophysical tool at a fixed location.

Technology status: Multiple implementations are available for neutron detectors. Existing ^{3}He proportional counters are costly and require high-voltage power supplies, but are high TRL. A developmental project called **DOWSER**, currently in a PICASSO program, offers an opportunity for a new technology that is low mass, low voltage, low power, and relatively insensitive to charged particles and gamma photons so that post-processing is not required to distinguish the neutron flux from other detection events. We plan to implement both traditional ^{3}He counters and DOWSER as a way to achieve rapid TRL maturation. As DOWSER matures, SNFLER can be implemented with less mass and resource cost, enabling many detectors to be deployed on individual roving units or astronauts as well as ground stations.

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