SINGR: A SINGLE SCINTILLATOR NEUTRON AND GAMMA-RAY SPECTROMETER FOR ACQUIRING RAPID, REMOTE GEOCHEMICAL DATA ON FUTURE PLANETARY SCIENCE MISSIONS

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Introduction: Geochemical planetary science data can be acquired at a variety of scales and play an important role constraining the geologic history of a planetary body, as well as in understanding formation and post-depositional processes experienced by local outcrops on a planetary surface. Several future NASA missions identified by the Planetary Decadal Survey would benefit from rapid acquisition of geochemical data, including a Venus lander, Moon or Mars rovers, and missions to comets, Phobos or Deimos. Acquiring lander- or rover-scale geochemical data on planetary surfaces is often achieved through robotic, arm-mounted instrumentation or via scoops/drills that sample a subset of near-surface material that is subsequently portioned to the instrument via a sample delivery system. These types of observations can require significant spacecraft resources (*i.e.* time, power) and often only a subset of bulk material can be characterized due to particle size or sample preparation limitations. Geochemical data can also be acquired through laser ablation spectroscopy, however, individual observations are typically at size scales on the order of ~microns, do not penetrate at significant depth, and are ideally suited for study of small-scale textures, minerals, or individual rocks. Observations at scales of several meters can integrate the geochemical signatures from multiple rock units and are typically sensitive to greater depths (tens of centimeters to meters) than other instruments. These measurements can be used to place other measurements in geologic context, to identify geochemical trends throughout a rover traverse, or for comparison with orbital (regional/planetary-scale) data sets.

The Curiosity Mars rover has successfully demonstrated the ability of an active-source neutron spectrometer (Dynamic Albedo of Neutrons (DAN)) to map multiple geologic units throughout an ~11km traverse in Gale Crater [1] DAN uses a new technique in planetary science called neutron die-away to rapidly assess H content and its distribution with depth. Using ^{3}He detectors and a pulsed neutron generator (PNG), DAN bins neutron counts by their energy and arrival time to acquire a high signal-to-noise measurement of neutron counts in ~20 minutes. The use of a PNG as a neutron source overcomes the limitation imposed by relatively low counting rates for gamma-rays and neutrons due to GCR reactions. For the Moon and Mars, there are about 9 neutrons created per GCR particle interaction with regolith, and typical gamma-ray fluxes produced by inelastic neutron scattering reactions vary between 0.1 - 2.6 photons/min-cm^2 for GCR-produced gamma rays [2]. A PNG can emit ~10^8 neutrons/s, greatly increasing the number of nuclear reactions in the subsurface, which will result in higher signal- to-noise (statistical uncertainty in count rate ~ $\sqrt{N}$) and significantly shortened measurement times [3]. As an example, DAN has acquired measurements with the PNG at every end-of-drive location utilizing short, 20

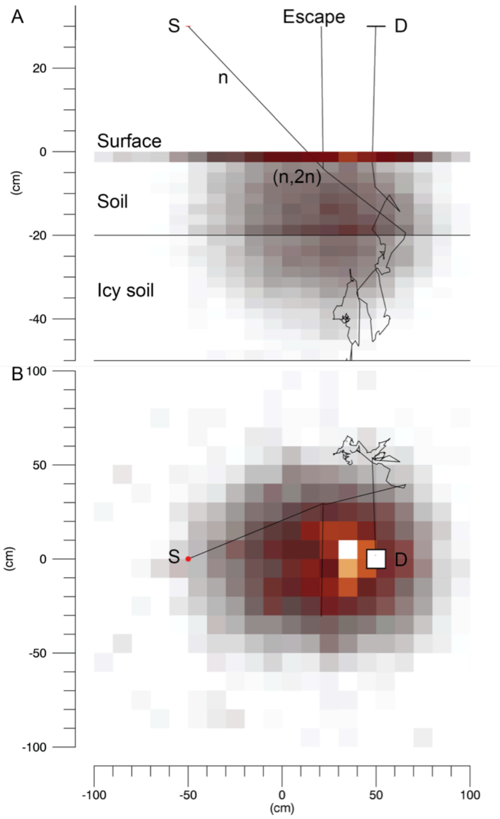

Figure 1. Measurement geometry and sample volume (temperature map) for active interrogation of an asteroid regolith with hydrogen layering, 1 wt.% water-equivalent hydrogen (WEH) covering 20 wt.% WEH. The source (**S**) is 14 MeV neutrons from a D-T pulsed neutron generator. The detector (D) is a 100 cm^2 × 2.5 cm CLYC scintillator. Side (A) and top (B) views of the geometry are shown along with a selected neutron trajectory.

minute observations. This has generated a significantly large data set of thermal and epithermal neutron counts over the first four years of surface operations [1, 4, 5]. Although not detected, characteristic prompt and delayed gamma-rays are produced by interactions of atomic nuclei with neutrons from the PNG are not detected by DAN's ^{3}He tubes. While other studies have demonstrated the use of individual neutron and gamma-ray detectors with a PNG [6,7,8], new high-efficiency scintillator materials that are sensitive to both neutrons and gamma-rays allow for one detector element to acquire counting data and spectra for both. One new scintillator material, CLYC, is an ideal candidate for use on future planetary science missions due to its sensitivity to thermal, epithermal and fast neutrons CLYC also provides gamma-ray resolution <4% at 662 keV [9,10].

Modeling: The objectives of our modeling effort are to support characterization of the response of CLYC to gamma-rays, neutrons, and energetic particles and to optimize the design of PNG-CLYC-based systems for in situ measurements of regolith composition and layering. For this purpose, we use a Monte Carlo radiation transport code [11] to sample particle interactions within a vehicle, regolith and detector. The detector response model includes a detailed treatment of light ouput, including quenching effects for swift electrons, protons, and ions produced by nuclear reactions (e.g. ^{6}Li(n,α)t in CLYC). Application of the code to determine the regolith volume sampled by 14 MeV neutrons is illustrated in **Fig. 1**.

Design: SINGR will utilize a 5cm dia. x 5cm long CLYC crystal coupled to a R6233-100 photomultiplier tube (PMT). The PMT is biased using a active voltage divider network to minimize non-linear behavior associated with high event rates. The predicted neutron flux based on the DAN measurements indicate that around 100 to 1000 ns after the neutron pulse will result in a 20-50% probability that more than one neutron will be detected in the crystal. This indicates that there will be some events that are piled up. To account for this, a signal processing algorithm will be implemented on the CLYC signals to identify separate neutron events. This algorthim is based on research [12] showing that CLYC can be used to discriminate neutrons from gamma rays at high gamma ray event rates exceeding 1x10^6 cps (**Fig. 2**).

The signal processing algorithm uses a simplied readout hardware, consisting of a buffer, differential amplifier, an analog to digital converter, and a field programmable gate array (FPGA). The front-end signal processing is conducted on the FPGA (filtering, trigerring, integration), and post-signal processing (energy conversion, particle type discrimination calculations, histogramming) are conducted on the processor. The system is designed to provide both neutron and gamma spectroscopy. The ability to detect both neutrons and gamma-rays on a single scintillator makes CLYC a compelling option for small spacecraft like CubeSats, such as the Lunar Polar Hydrogen Mapper (LunaH-Map) CubeSat mission, which will utilize a detector array of CLYC within its Miniature Neutron Spectrometer (Mini-NS) [13].

Future Work/Tests: Future tests will allow us to demonstrate the use of CLYC in an active configuration using a PNG. This prototype CLYC instrument will be tested in early 2017 using a commercial Thermo MF Physics Model MP320 D-T PNG at an outdoor test site at NASA/ Goddard Space Flight Center [14]. This test facility consists of two large (1.8 m x 1.8 m x .9 m) Columbia River basalt and Concord Gray granite test monuments located in the middle of an open field surrounded by a 50-meter radius radiation safety zone. The complete bulk elemental composition of both basalt and granite materials has been independently measured to ppm levels so that they will act as measurement standards for our tests. In addition, the test site provides thin plates of basalt, granite and polyethylene that can be layered on top of the monuments to physically simulate buried hydrogen-rich material at a specified depth. These tests will allow the CLYC instrument to measure the depth of this material as well as the bulk elemental composition of the monuments.

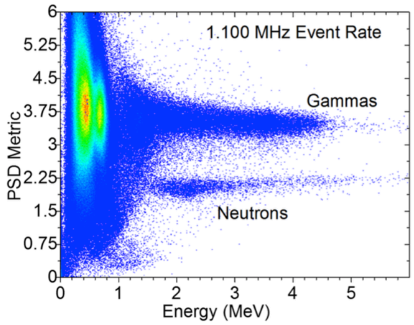

Figure 2: Pulse shape discrimination plot for CLYC with an AmBe and Cs-137 source at an event rate of 1100 kHz

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