ACTIVE NUCLEAR INVESTIGATIONS OF PLANETARY SURFACES WITH SINGR (SINGLE-SCINTILLATOR NEUTRON AND GAMMA RAY SPECTROMETER).

L. E. Heffern[1], C. Hardgrove[1], E. Johnson[2], A. Parsons[3], T. Prettyman[4], A. Jain[1], H. Barnaby[1], J. Christian[2], C. Tate[5], G. Stoddard[3], A. Martin[5], J. Moersch[5], [1]Arizona State University (School of Earth and Space Exploration, Tempe, AZ, Lheffern@asu.edu), [2]Radiation Monitoring Devices (RMD, Watertown, MA), [3]NASA Goddard Space Flight Center (Greenbelt, MD), [4]Planetary Science Institute (Tuscon, AZ) [5]University of Tennessee (Knoxville, TN).

Introduction: The hydrogen content and elemental composition of a planetary surface can be determined through the use of nuclear instrumentation (i.e. neutron spectrometers (NS) and gamma ray spectrometers (GRS)) [1]. Here we present developments and preliminary data from a new active nuclear instrument (selected in NASA PICASSO program) that uses a pulsed neutron generator to rapidly characterize the bulk geochemistry and hydrogen content of planetary surfaces. The SIngle-scintillator Neutron and Gamma Ray spectrometer (SINGR) can be used on future rovers or landers where the mission science goals include characterization of the hydrogen content, the depth distribution of hydrogen, and the bulk geochemistry of a planetary surface [2]. SINGR has undergone preliminary characterization with a PNG at the NASA Goddard Space Flight Center (GSFC) Geophysical and Astronomical Observatory (GGAO) outdoor gamma ray and neutron instrumentation testing facility. Here we report on the results of these tests.

Background: SINGR's neutron measurements can be used to place measurements from other instruments in geologic context via knowledge of spatial hydrogen content and abundance of neutron absorbing elements. Constructing a neutron die-away curve is a fairly new technique in planetary science that can rapidly assess hydrogen and its distribution with depth (~1 m radius) [2, 3]. Active-source neutron spectroscopy has already been successfully demonstrated by the DAN (Dynamic Albedo of Neutrons) instrument on board the Curiosity Mars rover; DAN has been used to map multiple geologic units throughout an ~11 km traverse in Gale Crater [4]. SINGR can be accommodated on a lander, rover, or drone which will collect data from the surface or at low-altitude ~1-2 meters. SINGR also detects gamma-rays in order to characterize the abundance of naturally occurring elements (K, Th, U), rock-forming elements (Si, Fe, O), and/or icy materials.

Instrumentation & Experiment: SINGR uses a relatively new scintillator material, an elpasolite called Cs_2YLiCl_6:Ce (CLYC) with high detection efficiency (neutrons) and energy resolution (gammas, 4% full-width-at-half-maximum at 662 keV). CLYC is capable of discriminating both neutrons and gamma-rays based on differences in the shape of the scintillator light-pulse, with the ^{6}Li(n,α)t reaction in CLYC allowing for the detection of neutrons [5]. For preliminary tests, we used a 3-in dia. x 3-in long cylindrical CLYC crystal coupled to a R6233-100 photomultiplier tube (PMT).

Two sets of data acquisition electronics capable of pulse shape discrimination (PSD) were used: a digital system with a field-programmable gate array (FPGA) developed by RMD and an analog system currently in development at ASU. The FPGA based system processes signals digitally after sampling at 250 MSPS and is more configurable, whereas the analog system is being designed for lower power consumption.

The PNG used for measurements is a commercial Thermo MF Physics Model MP320 DT neutron generator capable of producing up to 10^8 neutrons per second with a frequency range from 250 to 1000 Hz. Preliminary tests of the SINGR detector, electronics, and PNG were conducted at GSFC GGAO in late August of 2017; these tests were performed using the Colombia River basalt monument with varying amounts of polyethylene, cadmium, basalt, and lead blocks layered on top of and within the monument (Fig. 1) [6]. Altering the amount of polyethylene in layers simulates varying the water-equivalent-hydrogen (WEH) content with depth, while Cd and Pb can be inserted for shielding the detectors and PNG.

Figure 1: Outdoor test set-up at GSFC GGAO showing the basalt monument, poly blocks, the PNG, SINGR detector, and electronics.

Modeling: Initial modeling has been performed using a Monte Carlo N-Particle (MCNP) code to replicate the experimental test setup at GSFC and the detec-

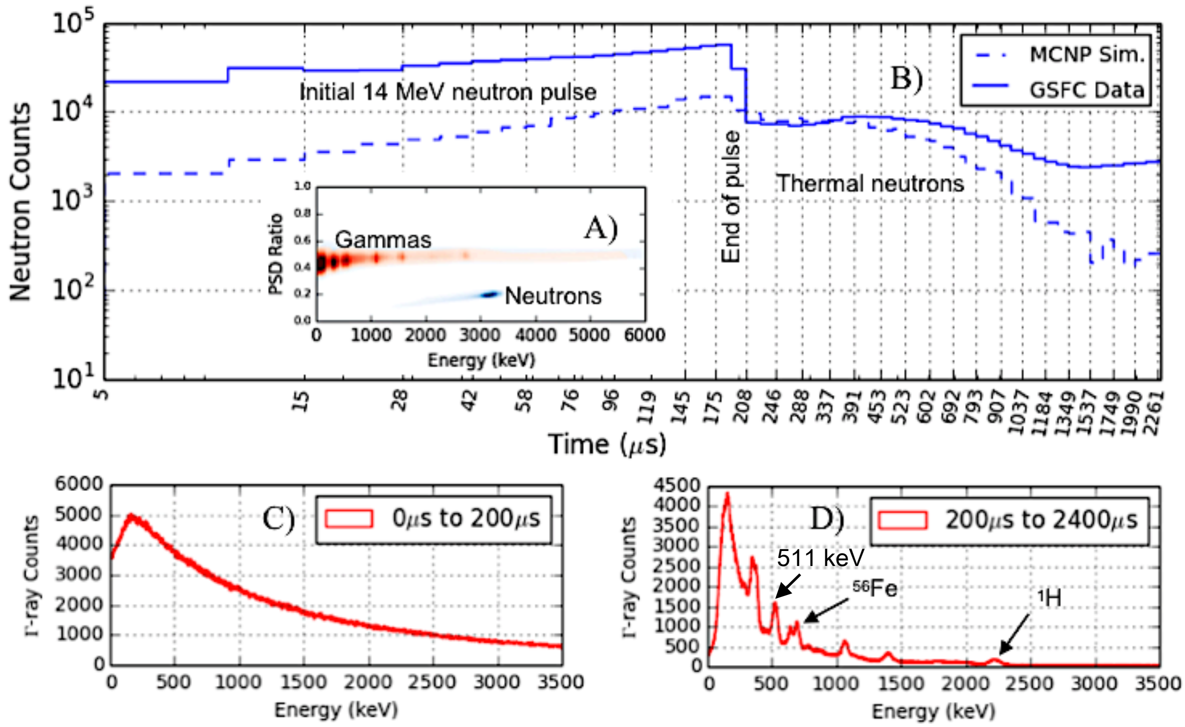

Figure 2: Preliminary results for an hour long PNG experiment with 10^7 neutrons per second pulsed at 250 Hz, with 2 inch thick polyethylene located under 20 cm of basalt: A) the resulting PSD plot (0 to 2400 µs), B) neutron die-away plot, c) gamma-ray plot during the pulse (0 - 200 µs), and D) gamma-ray plot after the pulse (200 - 2400 µs).

tor response. The objectives of the modeling effort are to support characterization of the response of CLYC to gamma-rays and neutrons, and to optimize the experimental design [2]. Modeling will assist in characterizing the WEH content present in the experimental setup.

Preliminary Results: Fig. 2 shows the data collected from an experiment using the basalt monument with 2-inch thick polyethylene blocks layered under 20 cm of basalt. The resulting PSD plot (Fig. 2A) shows all neutron and gamma-ray events collected within the one hour measurement integration. Fig. 2B shows the resulting neutron die-away curve from this experiment; every event has a time stamp, by extracting the neutron events based on the PSD ratio (0.12 to 0.28 via Gaussian fit) it is possible to construct the neutron die-away curve. An initial MCNP model is also shown that matches the shape of the die-away curve; note that the the experimental data may contain non-neutron events due to overlapping fits from the PSD ratio. This may account for the overall shape of the PSD plot (Fig 1A) as well as the discrepancy between the neutron die-away models and data. Gamma-ray spectra were acquired with SINGR both during and after the PNG pulse; the gamma-ray events were extracted from the data based on the PSD ratio (0.32 to 0.6). During the pulse (Fig. 2C) we would expect to see prompt gamma-rays, however, pile-up events dominate the spectrum and there are no identifiable lines. Immediately after the pulse, pile-up events cease and gamma-rays resulting from neutron capture can be identified (Fig. 2D). Previous calibrated gamma-ray spectra for the basalt monument from Bodnarik [6] was used for initial calibrations; hydrogen (2224 keV), iron (692 keV, ~4.1% energy resolution), and the 511 keV annihilation peak are preliminarily identified. Further analysis will consist of time binning gamma-ray peaks in order to identify elemental isotopic lines based on half-lives.

Future Work: At high event rates (> 10^6 neutrons/second) collected events can pile on top of each other in time, a phenomena called pulse pile-up [5]. Future work will include investigations of algorithms to de-construct and collect pulse pile-up events, eventually allowing for an increase in the detector's relative efficiency. Further experimental campaigns are scheduled for summer 2018 in order to further characterize the SINGR detector response and test elemental sensitivities in various planetary mission configurations.

References: [1] R. C. Reedy, 1987 Workshop on Nuclear Spectroscopy of Astrophysical Sources, [2] Hardgrove, et. al., 2016 Instrumentation for Planetary Missions Workshop, [3] T. S. J. Gabriel, et. al., in prep, [4] I. Mitrofanov, et. al., 2014 JGR-P, [5] E. Johnson, et. al., 2015 IEEE International Symposium, [6] J. Bodnarik, 2013 Vanderbilt University PhD Thesis.