Pulsed Neutron Experiments with SINGR (SIngle-scintillator Neutron & Gamma-Ray spectrometer)

L. E. Heffern (1), C. Hardgrove (1), E. Johnson (2), A. Parsons (3), R. Starr (4), T. Prettyman (5), H. Barnaby (1), J. Christian (2), C. Tate (6), G. Stoddard (2), A. Martin (6), J. Moersch (6)
(1) Arizona State University School of Earth and Space Exploration, Tempe, AZ, (2) Radiation Monitoring Devices, Watertown, MA, (3) NASA Goddard Space Flight Center Greenbelt, MD, (4) Catholic University of America, Washington DC, (5) Planetary Science Institute Tuscon, AZ, (6) University of Tennessee, Knoxville, TN. (Lheffern@asu.edu)

Abstract

Here we present results from a new active nuclear instrument (selected in 2015 NASA PICASSO program) that combines a dual neutron and gamma-ray sensitive scintillator with a pulsed neutron generator (PNG) to rapidly characterize the hydrogen (H) content, depth distribution of H, and bulk geochemistry of planetary surfaces [3]. The SIngle-scintillator Neutron and Gamma Ray spectrometer (SINGR) can also be used passively, without a PNG, and is designed for accommodation on future interplanetary rovers or landers.

1. Introduction & Background

Active neutron measurements can be used to rapidly (~tens of minutes) characterize the H content and its depth within the top meter of planetary surfaces using a PNG [1-3, 5-9]. Active neutron measurements have been made on Mars for the first time with the Dynamic Albedo of Neutrons (DAN) instrument on the *Curiosity* rover and have revealed H enrichments throughout the traverse, as well as hydrated silica phases within fractures, and helped place constraints on hydrated amorphous phases [2, 7]. Like DAN, SINGR's neutron measurements characterize the H content and abundance of neutron absorbing elements within the top meter of a planetary surface. SINGR enhances the current state of the art by providing bulk elemental analysis through use of a dual neutron and gamma ray detector system. Combining active neutron techniques with gamma-ray spectroscopy, which is sensitive to the abundance of naturally occurring elements (K, Th, U), rock-forming elements (Si, Fe, Mg), and/or icy materials, is the goal of several instrument development programs [1, 3, 5, 8, 9]. Time resolved active gamma-ray analysis, enabled by the use of a PNG, can also be used to better distinguish elemental abundances based on radiogenic decay [1, 9]. SINGR can be accommodated on a lander, rover, or drone which can collect data from the surface or at low-altitude ~1-2 meters. SINGR has undergone preliminary experimental 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.

2. Instrument & Experiment

SINGR uses a relatively new scintillator material, an elpasolite called Cs_2YLiCl_6:Ce (CLYC) that has a gamma-ray energy resolution of approximately 4% full-width-at-half-maximum at 662 keV; the $^6Li(n,\alpha)t$ reaction in CLYC allows for the detection of neutrons [4]. SINGR uses a technique called pulse shape discrimination (PSD) to detect neutrons and gamma-rays based on differences in the shape of the scintillator light-pulse. SINGR uses a three-inch diameter by three-inch long cylindrical CLYC crystal coupled to a Hamamatsu photomultiplier tube (PMT). The digital electronic system (sample rate ~ 250 megasamples per second) is a field-programmable gate array (FPGA) developed by RMD. The PNG used in testing was 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. SINGR testing was conducted using the Colombia River basalt monument at GSFC GGAO in late August of 2017 with follow-up tests performed in March 2018 [1, 9]. Plates of polyethylene, cadmium, and lead were used in a variety of configurations; by altering the amount of polyethylene in different layers within the basalt monument, we are able to simulate varying the H content with depth. Cd and Pb plates were placed in front of the detector to shield from low-energy (thermal) neutrons and x-rays.

3. Experimental Results

Data were collected using SINGR and a PNG at the basalt monument arranged with 2-inch thick polyethylene plates layered under 20 cm of basalt. After the initial 14 MeV neutron pulse, neutrons and gamma-rays are emitted from the target surface. Fig. 1 shows resulting neutron die-away curves from two of our experiments, one with Cd plates in front of the detector (green) and one without (blue). There is a drop in the thermal neutron count rate when Cd plates are used to shield the detector, this is due to Cd's high probability to absorb thermal neutrons, thus making the detector sensitive to only epithermal neutrons. The calculated difference between the thermal+epithermal and the epithermal neutrons results in the thermal neutron data (red) that is used to infer the H content and H depth distribution.

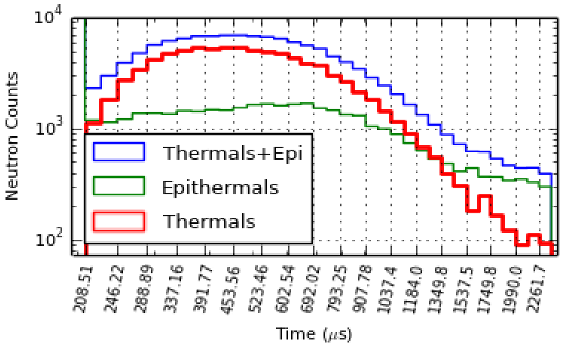

Figure 1: Neutron die-away curves (200 – 2500 µs, after initial 14 MeV neutron pulse) of the basalt monument showing thermal+epithermal (blue), epithermal (green), and thermal (red) neutrons.

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 PSD. Immediately after the pulse (200 – 2500 µs), pile-up events are significantly reduced and gamma-rays resulting from neutron capture and delayed neutron activation can be identified (Fig. 2). Previous high-purity germanium GRS data of the basalt monument from Bodnarik [1] were used to identify and calibrate SINGR during these tests; several elemental (stable isotope) lines, including Fe (692 keV, 4.1% energy resolution), O (~ 6 MeV triplet), and Si (1.79 MeV) are identified. The experimental set-up also includes an aluminum scaffolding which is associated with the doppler-broadened gamma-ray peak (2000 – 2500 keV energy region) present in our data.

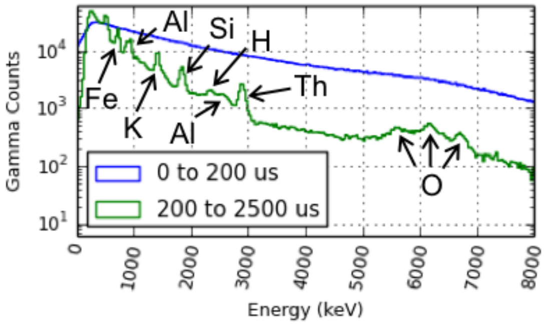

Figure 2: Gamma-ray spectra of the basalt monument acquired between-PNG pulses (green line: 200 – 2500 µs) and during the PNG pulses (blue line).

4. MCNP Simulations

The Monte Carlo N-Particle (MCNP6) transport code has been used to simulate the detector response and the basic experimental test parameters at GSFC. We will be able to compare the H content and elemental abundances we derive from MCNP6 with the known (ground-truth based on mass spectroscopy and x-ray fluorescence sample testing) values from making neutron and gamma-ray measurements of those quantities at the test site using SINGR. Simulations of the instrument response and test setup will be used to determine sensitivities and optimize detector configurations for future experiments.

5. Summary & Conclusions

We have successfully demonstrated that SINGR can be used to construct neutron die-away curves and collect gamma-ray spectra between PNG pulses. Further experiments will be completed in spring and summer of 2019 in order to fully characterize the SINGR detector response and test elemental sensitivities for other relevant planetary mission environments.

References

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