PLANETARY GEOCHEMISTRY TECHNIQUES: PROBING IN-SITU WITH NEUTRON AND GAMMA RAYS (PING) INSTRUMENT. A. Parsons[1], J. Bodnarik[1,2], D. Burger[2], L. Evans[1,3], S. Floyd[1], L. Lim[1], T. McClanahan[1], M. Namkung[1], S. Nowicki[1,4], J. Schweitzer[5], R. Starr[1,6], J. Trombka[1,7]
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Introduction: The **P**robing **In** situ with **N**eutrons and **G**amma rays (**PING**) instrument is a promising planetary science application of the active neutron-gamma ray technology so successfully used in oil field well logging and mineral exploration on Earth. The objective of our technology development program at NASA Goddard Space Flight Center's (NASA/GSFC) Astrochemistry Laboratory is to extend the application of neutron interrogation techniques to landed *in situ* planetary composition measurements by using a 14 MeV Pulsed Neutron Generator (PNG) combined with neutron and gamma ray detectors, to probe the surface and subsurface of planetary bodies without the need to drill. We are thus working to bring the PING instrument to the point where it can be flown on a variety of surface lander or rover missions to the Moon, Mars, Venus, asteroids, comets and the satellites of the outer planets.

PING represents the first time a PNG has been combined with both neutron and gamma ray detectors to create a landed instrument that can determine bulk surface and subsurface elemental composition and mineralogy without needing to alter the planetary surface in any way. We have had great success demonstrating PING's capabilities at our unique outdoor neutron instrumentation test facility located at NASA/GSFC. We will present recent results from PING composition measurements made in a variety of experimental configurations on a known sample in a geometry that is identical to that which can be achieved on a planetary surface. We will then compare the PING composition results to a trace elemental composition analysis performed by an independent laboratory. Finally, we will demonstrate the improved elemental sensitivity achieved by our ability to separate the gamma ray spectral lines by the nuclear process that generated them

Principles of PING Operation: PING consists of three basic components: 1) a pulsed neutron generator (PNG) that emits intense pulses of fast (14 MeV) neutrons to excite materials at and below the planetary surface, 2) a gamma ray spectrometer to measure the characteristic gamma rays from the excited elements and 3) neutron detectors to measure the properties of the resulting lower energy epithermal and thermal neutrons that reach the surface.

When a planetary surface is bombarded with 14 MeV neutrons from PING's neutron generator, the nuclei in the planetary materials at and below the surface will be excited so that they emit gamma radiation characteristic of the elements present. The intensity of these gamma ray lines as measured by the gamma ray spectrometer yields the abundance of each element in the material. Since the scattering of neutrons in the material is strongly dependent on its hydrogen content, measurements of the thermal and epithermal neutron flux at the planet's surface provide an extremely sensitive measurement of the bulk hydrogen content of the planetary material. Because neutron and gamma radiation are so penetrating, PING will be able to determine the local bulk elemental abundances and mineralogy with a spatial resolution of 1 m and down to depths of tens of cm to 1 m below the surface. PING can detect a wide variety of elements and measure their bulk concentration with high precision. Accessible elements include, but are not limited to, C, H, O, P, S, Si, Na, Ca, Ti, Fe, Al, Cl, Mg, Mn, V and the naturally radioactive elements K, Th, and U.

A great advantage of using a pulsed neutron generator is the ability to identify the nuclear process (inelastic scattering, thermal neutron capture or delayed activation) that is responsible for specific gamma ray lines in the spectrum. We will show how identifying the nuclear process by the gamma rays' arrival time relative to the PNG pulse is used to simplify the spectral analysis and improve sensitivity.

Experimental Description: Our PING prototype instrument tests are conducted at a unique neutron instrument test facility located at Goddard's Geophysical

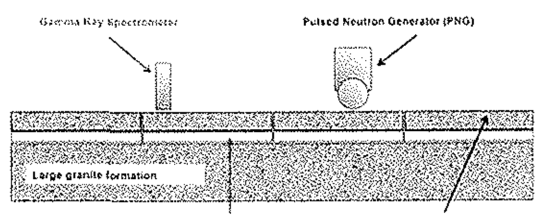

Figure 1:This illustration of our basic experimental configuration shows how layers of different materials can be constructed to simulate different subsurface planetary composition profiles. Here we demonstrate our ability to detect subsurface water ice by placing a 2.5 cm layer of high-density polyethylene beneath a layer of 5 cm thick granite blocks.

and Astronomical Observatory (GGAO) near GSFC's main campus [1]. At our GGAO test site, we have the capability to test PING using known sample materials in a geometry that is similar to that of future planetary *in situ* applications. The test samples are thus located outdoors 50 m from the nearest structure. The site currently offers a single 1.8 m x 1.8 m x 0.9 m granite sample formation, but an identically sized Columbia River basalt sample will be installed in early Spring 2011. The meter-scale size of these samples match typical neutron and gamma ray penetration distances and ensure that the 14 MeV neutrons emitted by the PNG interact only in this sample and in no other material in its environment.

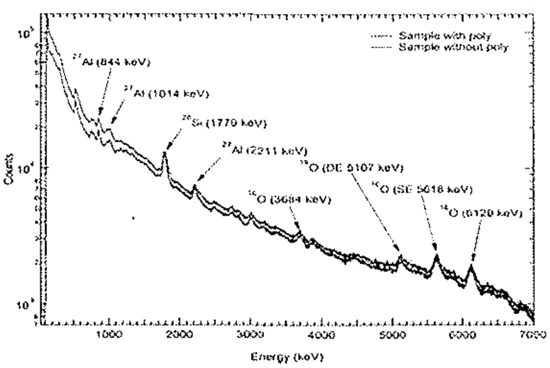

Figure 2: Spectra obtained during the pulse of high-energy neutrons with and without the presence of polyethylene.

These sample materials were chosen because they have uniform composition on the appropriate size scale, can be easily characterized, and have low porosity so that their water content is stable and independent of Maryland weather. The pairing of our granite with a basalt sample allows us to test PING on materials representative of a variety of bodies in the solar system. Due to the PNG radiation safety hazard, we operate PING remotely from a building over 60 m away.

Our tests involve placing our PING prototype on top of a large test sample (see Figure 1) to measure the resulting characteristic gamma rays and epithermal and thermal neutrons radiated by the surface. We also have the capability to perform layering studies using 5 cm thick plates of the same sample materials as well as 2.5 cm thick high-density polyethylene plates to simulate layers of water ice. These materials and others can be stacked on top of the test sample to simulate a variety of layering and composition scenarios.

Results: The spectra shown in Figure 2 illustrate the power of gated data acquisition to isolate gamma rays from different nuclear processes. With our PNG and a LaBr gamma ray spectrometer on top of our granite formation as shown in Figure 1, we were able to use a single data acquisition window fixed at a time during each neutron burst to isolate a gamma ray spectrum that is primarily due to "inelastic" high-energy interactions. These "inelastic" spectra shown in Figure 2 result from two experiments, one with 2.5 cm of polyethylene on top of the granite and covered with granite plates and one without polyethylene. Since polyethylene is a good source of hydrogen, its presence more quickly moderates neutrons. The capture background shown in the inelastic spectrum with the polyethylene is slightly lower because fewer thermal neutrons are present from earlier bursts. The lack of evidence of the 3539 keV neutron capture line from Si, for example, illustrates how well this technique isolates the gamma rays from inelastic processes.

Timing Studies: In addition to time-gated gamma ray data acquisition spectra, we now have the ability to take timed tagged event–by-event data using our custom designed software with the Canberra Lynx Digital Signal Analyzer to provide a unique three-dimensional master data set with channel/energy, time, and intensity information. Since the master data set is not limited to predetermined coincidence timing gates set for a specific nuclear process, the user is allowed the flexibility to slice the data cube in a multitude of ways without loss of information or experimental time due to the need for additional acquisition windows. Time-tagged event-by-event data allows the user to analyze a gamma ray spectrum resulting from either neutron capture, events occurring between the neutron pulses, or inelastic scattering events occurring during the neutron pulse, and extract the data needed to optimize timing windows to look at specific elements in different environments. For example, the water content on Mars (~3%) is greater than that on the Moon (<1%). This difference affects the slowing down time of neutrons on the Moon and thus requires a greater delay of the start of the neutron capture time window with respect to the end of the PNG pulse. We will present the results of our experimental data using the time tagged event-by-event data analysis technique compared to time gated coincidence data. Comparison of these data will show the advantages and validity of this method to obtain more precise and sensitive elemental composition measurements.

Conclusions: The spectra in Figure 2 demonstrate the capabilities of PING as well as the great flexibility available for the testing of this device in a controlled environment. We will compare the granite composition inferred from these data with the independent elemental composition analysis and the results of our computer models. We will also present additional data to further illustrate the utility of gated data acquisition.

References: [1] Bodnarik, et al., LPSC 2010 #2581