ACTIVE NEUTRON AND GAMMA RAY INSTRUMENTATION FOR *IN SITU* PLANETARY SCIENCE

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Introduction: The Pulsed Neutron Generator-Gamma Ray And Neutron Detectors (PNG-GRAND) experiment is an innovative 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 active neutron-gamma ray technology program at NASA Goddard Space Flight Center (NASA/GSFC) is to bring the PNG-GRAND 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.

Gamma-Ray Spectrometers (GRS) have been incorporated into numerous orbital planetary science missions and, especially in the case of the Mars Odyssey GRS, have contributed detailed maps of the elemental composition over the entire surface of Mars. However, orbital gamma ray measurements have low spatial sensitivity (100's of km) due to their low surface emission rates from cosmic rays and subsequent need to be averaged over large surface areas. PNG-GRAND overcomes this impediment by incorporating a powerful neutron excitation source that permits high sensitivity surface and subsurface measurements of bulk elemental compositions.

PNG-GRAND combines a pulsed neutron generator (PNG) with gamma ray and neutron detectors to produce a landed instrument to determine subsurface elemental composition without needing to drill into a planet's surface – a great advantage in mission design. We are currently testing PNG-GRAND prototypes at a unique outdoor neutron instrumentation test facility recently constructed at NASA/GSFC that consists of a 2 m x 2 m x 1 m granite structure placed outdoors in an empty field. Because an independent trace elemental analysis has been performed on the material, this granite sample is a known standard with which to compare both Monte Carlo simulations and our experimentally measured elemental composition data.

We will present data from operating PNG-GRAND in various experimental configurations on a known sample in a geometry that is identical to that on a planetary surface. We will also illustrate the use of gamma ray timing techniques to improve sensitivity and will compare the material composition results from our experiments to both an independent laboratory elemental composition analysis and MCNPX computer modeling results.

Principles of PNG-GRAND Operation: PNG-GRAND 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 emitted by the excited ele-

ments and 3) neutron detectors to measure the properties of the resulting lower energy epithermal and thermal neutrons that reach the surface. The technology used for these individual PNG-GRAND components depends on both performance requirements and on the mass, power, volume and budgetary constraints of a particular mission. Part of our instrument development research is to match mission performance requirements with the attributes of gamma ray and neutron detector technologies to optimize scientific return.

When a planetary surface is bombarded with 14 MeV neutrons from the PNG, the nuclei in the planetary materials below the surface are 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 can be used to determine the absolute abundance of each element in the material. Also, neutron are scattered within the material and a measurement of the surface thermal and epithermal neutron flux provides the bulk hydrogen content in the surface material. While resting on the surface of any solar system body, PNG-GRAND will be able to detect a wide variety of elements and measure their absolute bulk concentration with high precision. Accessible elements include C, H, O, P, S, Si, Na, Ca, Ti, Fe, Al, Cl, Mg, Mn, V and the naturally radioactive elements K, Th, and U.

Experimental Description: It is important to test the capabilities of PNG-GRAND prototypes on a known sample material in the same geometry as that of future planetary *in situ* applications. PNG-GRAND tests are conducted at a unique test facility at Goddard's Geophysical and Astronomical Observatory (GGAO) site near GSFC's main campus [1]. Here, we place a PNG-GRAND prototype on top of our large granite test sample to measure the resulting characteristic gamma rays and epithermal and thermal neutrons from the material. The meter-scale size of our granite sample matches typical neutron and gamma ray penetration distances and thus ensures that the 14 MeV neutrons emitted by the PNG interact primarily in this sample with very few interactions occurring in the other materials in its environment. With a 50 m radius keep-out zone, we can remotely operate PNG-GRAND without creating a radiation safety hazard or detecting background signals from neutron and gamma ray interactions with nearby structures. PNG-GRAND is operated remotely from a building over 60 m away.

Our facility allows us to perform layering studies using 5 cm thick granite plates and 2.5 cm thick high-density polyethylene plates to simulate layers of water ice. These and other materials can be stacked on top of the large test
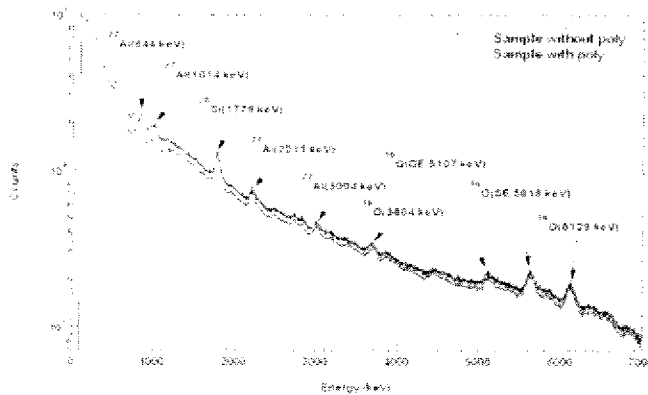
Figure 1: These data were taken in a time window within the neutron pulse and thus consists primarily of gammas from inelastic scattering processes.

sample to simulate a variety of layering scenarios. The experimental data presented here were taken both with and without the polyethylene layer.

Time-Gated Gamma Ray Spectra: A great advantage of using a PNG is the ability to identify the nuclear process (inelastic scattering, thermal neutron capture, delayed activation or natural radioactivity) that is responsible for specific gamma ray lines in the spectrum. The experiment is controlled by multiple Digital Signal Analyzers [2] that permit operation in event-by-event time stamped list mode. With the detection time of gamma ray known, it is possible to select events by their detection time with respect to the neutron pulse and produce separate gamma ray spectra for different time windows. Since there is a time delay in the emergence of thermal neutron capture gamma rays as the material moderates the 14 MeV neutrons, we can use the event arrival time to identify the gamma rays resulting from the different nuclear processes. The ability to isolate gamma rays by their timing will improve the instrument sensitivity tremendously and is a valuable tool for identifying interfering spectral peaks. Using this technique with different gamma ray spectrometer technologies we will show how identifying the nuclear process by the gamma rays' arrival time relative to the PNG pulse simplifies the spectral analysis and improves sensitivity.
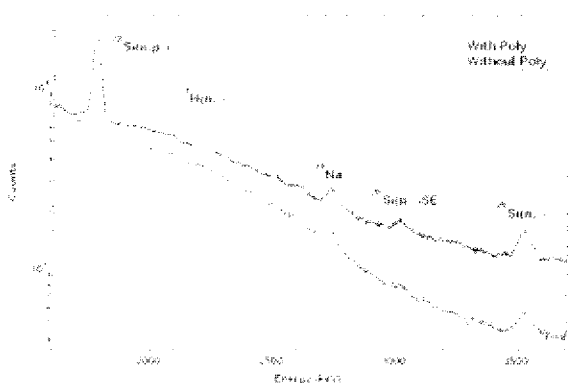

Figure 2: These data were taken in a 625 μs time gate beginning 125 μs after the neutron pulse. This delay gives fast neutrons time to slow down, so this spectrum is dominated by gamma rays from the neutron capture process. The absence of the hydrogen line when there is no polyethylene shows this technique can measure subsurface hydrogen.

MCNPX Computer Simulations: Computer simulations of potential PNG-GRAND configurations are performed using the Monte Carlo N-Particle eXtended (MCNPX) transport code described in [3]. This application has the dual benefit of providing both an efficient framework for hardware system design and optimization and a crucial link between theoretical results and experimental observations. Current models have incorporated and simulated the detailed granite composition, the PNG and the specific gamma ray and neutron detectors used in our experiments.

Results: With PNG-GRAND on top of our granite formation, we can demonstrate our ability to detect a layer of HD polyethylene 5 cm beneath the surface. By selecting gamma ray data according to the time of arrival between the neutron bursts, we are also able to isolate gamma ray spectra primarily due to inelastic scattering (Figure 1); and thermal neutron capture (Figure 2). We made measurements both with and without 2.5 cm of polyethylene on the granite and covered with 5 cm granite plates. The absence of hydrogen when the polyethylene is not present demon-
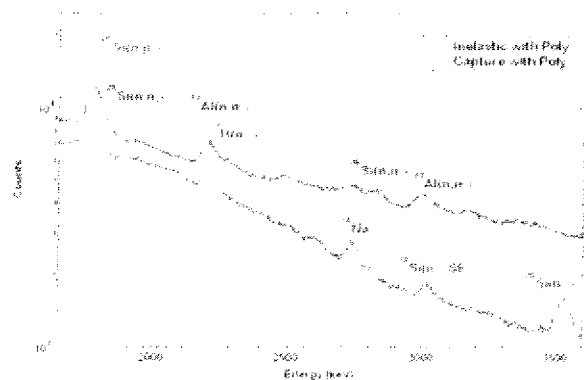

Figure 3: This comparison of inelastic and capture gamma ray spectra with the polyethylene present illustrates how the ability to separate gamma ray spectral data by nuclear process allows for better element identification for improved sensitivity.

strates the ability of this technique to measure subsurface hydrogen. The lack of evidence of the 3539 keV capture line from Si in the inelastic spectrum shown in Figure 3 illustrates how well this technique isolates the gamma rays from inelastic processes. This presentation of real data provides an excellent demonstration of the PNG-GRAND concept as well as device testing capabilities.

We will present additional data to further illustrate the utility of gated data acquisition. We will also compare the granite composition inferred from these data with the independent elemental composition analysis and the results of our computer models.

References: [1] Bodnarik, *et al.*, "A Unique Outside Neutron and Gamma Ray Instrumentation Development Test Facility at NASA's Goddard Space Flight Center", LPSC XLI:2581; [2] the Lynx Digital Signal Analyzer from Canberra; [3] Pelowitz, D. E., (Ed.) 2008, MCNPX User's Manual, Doc. LA-CP-07-1473, Los Alamos Natl. Lab., Los Alamos, NM