

PLANETARY GEOCHEMISTRY USING ACTIVE NEUTRON AND GAMMA RAY INSTRUMENTATION. A. Parsons¹, J. Bodnarik¹, L. Evans^{1,2}, S. Floyd¹, L. Lim¹, T. McClanahan¹, M. Namkung¹, J. Schweitzer³, R. Starr^{1,4}, J. Trombka^{1,5}

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Introduction: The Pulsed Neutron Generator-Gamma Ray And Neutron Detector (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 have been incorporated into numerous orbital planetary science missions and, especially in the case of Mars Odyssey, have contributed detailed maps of the elemental composition over the entire surface of Mars. Neutron detectors have also been placed onboard orbital missions such as the Lunar Reconnaissance Orbiter and Lunar Prospector to measure the hydrogen content of the surface of the moon. The DAN *in situ* experiment on the Mars Science Laboratory not only includes neutron detectors, but also has its own neutron generator. However, no one has ever combined the three into one instrument. PNG-GRAND combines a pulsed neutron generator (PNG) with gamma ray and neutron detectors to produce a landed instrument that can determine subsurface elemental composition without drilling. We are testing PNG-GRAND at a unique outdoor neutron instrumentation test facility recently constructed at NASA/GSFC

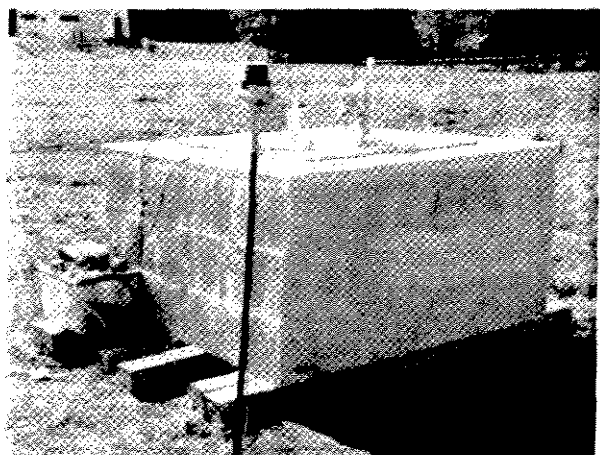


Figure 1: Experimental configuration with our PNG and a LaBr_3 gamma ray spectrometer on top of the granite formation at our test site.

that consists of a 2 m x 2 m x 1 m granite structure in an empty field. We will present data from the operation of PNG-GRAND in various experimental configurations on a known sample in a geometry that is identical to that which can be achieved on a planetary surface. We will also compare the material composition results inferred 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 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 these 14 MeV neutrons from the neutron generator, the nuclei in the planetary materials both 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 absolute abundance of each element in the material. Neutrons are scattered from the material and measurement of the 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.

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: It is important to test the capabilities of PNG-GRAND prototypes on a known sample material in a geometry that is similar to that of future planetary *in situ* applications. PNG-GRAND tests are conducted at a unique test facility

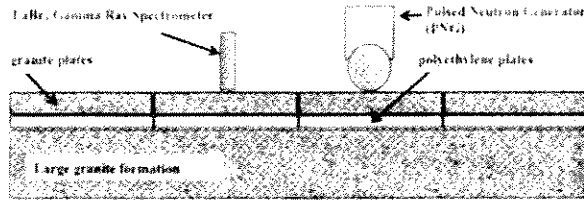


Figure 2: Layered geometries can be simulated by placing other materials between the granite formation and our granite plates. Here we simulate a water/ice layer below the surface using plates of polyethylene.

located 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 a large test sample to measure the resulting characteristic gamma rays and epithermal and thermal neutrons from the surface. To ensure that the 14 MeV neutrons emitted by the PNG interact only in this sample and in no other material in its environment, the sample size must be on the meter-scale to match typical neutron and gamma ray penetration distances. As shown in Figure 1, we have chosen to use 2 m x 2 m x 1 m of granite as our sample formation. This material was chosen because it is readily available, has uniform composition on the appropriate size scale, can be easily characterized, and has low porosity so that its water content is stable and independent of Maryland weather. 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.

An additional feature of our facility is the ability 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 materials can be stacked on top of the large granite test sample to simulate a variety of layering scenarios. The experimental data presented here was taken in the configuration illustrated in Figure 2 both with and without the polyethylene layer.

MCNPX Computer Simulations: Computer simulations of potential PNG-GRAND configurations are performed using the Monte Carlo N-Particle extended (MCNPX) transport code described in detail in [2]. 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: Using our PNG and a LaBr₃ gamma ray spectrometer on top of our granite formation, we were

able to take actual proof-of-concept data that illustrates gated data acquisition. Using a single data acquisition window fixed at a time during each neutron burst, we isolate a gamma ray spectrum that is primarily due to "inelastic" high-energy interactions. These measured "inelastic" spectral data are shown in Figure 3. We performed 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 capture line from Si, for example, 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.

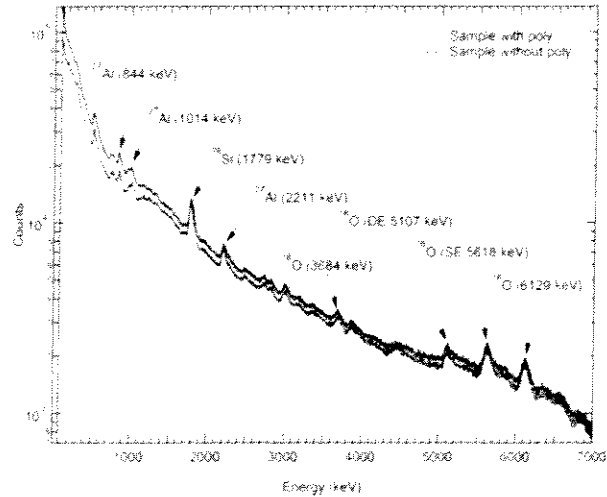


Figure 3: Spectra obtained during the pulse of high-energy neutrons with and without the presence of polyethylene. The peaks due to "inelastic" interactions are the same, but the background due to thermal neutron capture is slightly lower

Conclusions: The data in Figure 3 demonstrate the capabilities of the PNG-GRAND concept as well as the great flexibility available for the testing of this device in a controlled environment. 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 2010; [2] Pelowitz, D. E., (Ed.) 2008, MCNPX User's Manual, Doc. LA-CP-07-1473, Los Alamos Natl. Lab., Los Alamos, NM