Development of the Probing In-Situ With Neutron And Gamma Rays (PING) Instrument for Planetary Science Applications

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Introduction: The **P**robing **I**n situ with **N**eutrons and **G**amma rays (**PING**) instrument [1] is a promising planetary science application of the active neutron-gamma ray technology that has been used successfully in oil field well logging and mineral exploration on Earth for decades. Similar techniques can be very powerful for non-invasive *in situ* measurements of the subsurface elemental composition on other planets. The objective of our active neutron-gamma ray technology program at NASA Goddard Space Flight Center (NASA/GSFC) is to bring instruments using this technology to the point where they 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 combines a 14 MeV deuterium-tritium pulsed neutron generator with a gamma ray spectrometer and two neutron detectors to produce a landed instrument that can determine the elemental composition of a planet down to 30 – 50 cm below the planet's surface. The penetrating nature of .5 – 10 MeV gamma rays and 14 MeV neutrons allows such sub-surface composition measurements to be made without the need to drill into or otherwise disturb the planetary surface, thus greatly simplifying the lander design. We are currently testing a PING prototype at a unique outdoor neutron instrumentation test facility at NASA/GSFC that provides two large (1.8 m x 1.8 m x .9 m) granite and basalt test formations placed outdoors in an empty field. Since an independent trace elemental analysis has been performed on both the Columbia River basalt and Concord Gray granite materials, these samples present two known standards with which to compare PING's experimentally measured elemental composition results.

We will present experimental results from PING measurements of both the granite and basalt test formations and show how and why the optimum PING instrument operating parameters differ for studying the two materials.

Principles of Operation: An active neutron – gamma ray instrument 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 elements and 3) neutron detectors to measure the resulting lower energy epithermal and thermal neutrons that reach the surface. To improve elemental sensitivity by reducing background, aiding in gamma ray line identification and studying the neutron moderation properties in the material, both the energy and the time of each neutron and gamma ray event between PNG pulses is measured by the PING electronics and is used in the analysis of the data.

When a planetary surface is bombarded with 14 MeV neutrons from the PNG, the nuclei in the planetary materials down to ~ 50 cm 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, neutrons are scattered within the material and a measurement of the surface thermal and epithermal neutron flux indicates the bulk hydrogen content in the surface material. On the surface of any solar system body, active neutron – gamma ray instruments will be able to detect a wide variety of elements and measure their absolute bulk concentration with high

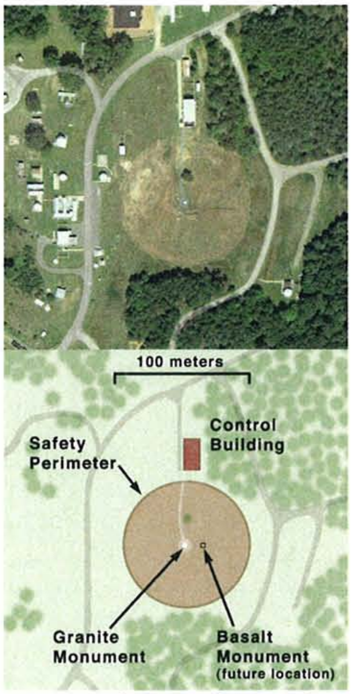

Figure 1: This aerial view of our neutron instrumentation test site shows the 50 m radius radiation safety perimeter surrounding the granite sample, and the basalt sample (to be delivered in June, 2011) as well as the nearby building used for remote operations.

Element	Concord Gray Granite	Columbia River Basalt
	wt% fraction	wt% fraction
C	0.03	0.03
S	< 0.01	0.01
Cl	0.02	0.04
H	0.087	0.00
N	0.01	0.01
Si	34.59	23.18
Al	7.32	8.64
Fe	1.00	7.34
Mn	0.04	0.12
Mg	0.17	4.79
Ca	0.62	6.62
Na	2.23	2.45
K	4.28	0.95
Ti	0.14	0.90
P	0.09	0.18
O	48.59	44.97
V	0.001	0.022
Cr	< 0.002	0.035
Ni	< 0.002	0.015

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.

Description of the Neutron and Gamma Ray Instrumentation Test Facility:

The test facility at GSFC's Geophysical and Astronomical Observatory (GGAO), shown in Fig. 1, consists of the large basalt and granite test formations located in the middle of an open field surrounded by a 50-meter radius radiation safety perimeter. Operating outdoors in a large empty field minimizes the background due to neutron and gamma ray interactions with nearby structures. The facility is equipped with a nearby operations building that provides power and communications to both the basalt and granite monuments so that users can operate and monitor PING at a safe distance from its neutron generator. The radiation safety perimeter is visually monitored during operation.

The Importance of Testing PING Using Both Granite and Basalt

Both granite and basalt are igneous rocks containing large amounts of silicon and oxygen. While granite forms when magma cools slowly beneath a planet's crust, basalt forms when deeper magma breaks through the crust, such as through a volcano, and then cools quickly on the surface. Because basalts are formed from deeper magma, they contain significantly more of the heavier elements such as iron and magnesium than granite. When PING is able to measure the elemental composition of a planet's surface with sufficient precision to differentiate between different kinds of basalt, it will become a very effective tool for studying the composition of a planet's mantle as well as local igneous processes. The first step toward this goal is to test PING with both basalt and granite and make sure that it can differentiate between these extremes in iron composition. As our techniques mature and we learn to optimize PING for sensitivity to higher iron content, the precision in PING's material composition measurements will greatly improve.

Experimental Description

The table above shows the elemental composition of our granite and basalt monuments as determined by an independent chemical assay [2] of each material. As expected, the basalt has a significantly greater amount of iron and magnesium than the granite.

Since elements like iron have a higher cross section for interaction with neutrons than other rock-forming elements such as oxygen and silicon, the 14 MeV neutrons from PING's PNG will interact more immediately with materials containing a large amount of iron, thus the spatial distribution of neutron interactions with depth and the time it takes for the neutrons to interact in the material thus differ significantly between the granite and the basalt. As a result, both the intensity and the pulsed time profile of the neutron and gamma ray emission measured by PING will differ greatly for the 2 materials. However, since PING measures both event time and energy for both gamma rays and neutrons, we will be able to study the differences in the gamma ray and neutron signal decay time between PNG pulses as well as differences in the overall gamma ray intensity. By analyzing simultaneous time and energy data for gamma rays and neutrons, we will be able to optimize PING's operational parameters such as the PNG pulse width and pulse period for the best elemental sensitivity in each case. We will present experimental data showing how the PING gamma ray and neutron signatures differ for the two materials as well as the optimum operating parameters for superior sensitivity for each material. By understanding PING's behavior when measuring both a granite and a basalt of precisely known composition, we can prepare to measure unknown samples in later field campaigns to demonstrate PING's ultimate capabilities.

References: [1] A. Parsons, *et al.*, "Active Neutron And Gamma-Ray Instrumentation For In Situ Planetary Science Applications", Nucl. Instr. and Meth. A(2010), doi:10.1016/j.nima.2010.09.157; [2] Elemental assays were performed by Actlabs a division of Activation Laboratories, Ltd. in Ontario, Canada