VENUS BULK ELEMENTAL COMPOSITION MEASUREMENTS WITH PING.

A. M. Parsons[1], J. Grau[2], T. P. McClanahan[1], J. Miles[2], L. Perkins[3], J. S. Schweitzer[4] and R. D. Starr[1,5]
[1]NASA Goddard Space Flight Center, Code 691, Greenbelt, MD 20771, Ann.M.Parsons@nasa.gov, [2]Schlumberger Doll Research Center, Cambridge, MA 02139, [3]Schlumberger Princeton Technology Center, Princeton Junction, NJ 08550, [4]University of Connecticut, Storrs, CT 06269, [5]Catholic University of America, Washington, DC 20064.

Introduction: The Probing In situ with Neutrons and Gamma rays (PING) instrument is ideally suited for performing fast bulk elemental composition measurements of the near subsurface of Venus. PING uses high energy neutrons and gamma rays to penetrate Venus' surface and measure the bulk elemental composition over a large volume beneath a landed probe (~30 cm deep, ~50 cm radius). Because neutrons and gamma rays can penetrate the pressure vessel walls, PING can be located completely inside the Venus lander. PING has no moving parts and does not require any sample manipulation or window.

Knowing the bulk elemental composition of the Venus surface material is important because it can tell us how Venus evolved and differentiated over time. Is the crust nearly all basalt or are there significant volumes of more differentiated (silica-rich) crust? PING can measure the abundances of both major and minor rock forming elements such as H, C, Na, Mg, Al, Si, S, P, Cl, Ca, Ti and Fe. PING can also make measurements of the naturally radioactive elements, K, U, and Th to evaluate the radiometric heat-producing element content of the crust to better constrain its bulk composition, differentiation and thermal evolution. Little is known about the bulk composition of the near subsurface of Venus. While surface x ray fluorescence measurements were made by the Venera and Vega missions in the 1970s-80s, gamma ray bulk composition measurements were limited to the naturally radioactive elements[1,2]. With the addition of a pulsed neutron generator, PING provides a significant improvement over previous Venus bulk composition studies.

Instrument Description: PING consists of a Pulsed Neutron Generator (PNG) and a Gamma-Ray Spectrometer (GRS), as shown in Figure 1. The PNG emits isotropic pulses of 14 MeV neutrons that are energetic enough to penetrate the pressure vessel walls, the dense atmosphere and Venus' surface. Nuclear reactions occur between these incident energetic neutrons and Venus's subsurface material that produce gamma rays with energies specific to the element and nuclear process involved. Thus the energies of the detected gamma rays identify the elements present and their intensity provides the abundance of each element. These gamma rays are energetic enough (0.1–10 MeV) to penetrate the Venus surface, atmosphere and pressure vessel walls to be detected by PING's lanthanum bromide ($LaBr_3$) scintillator GRS. The GRS spectra are

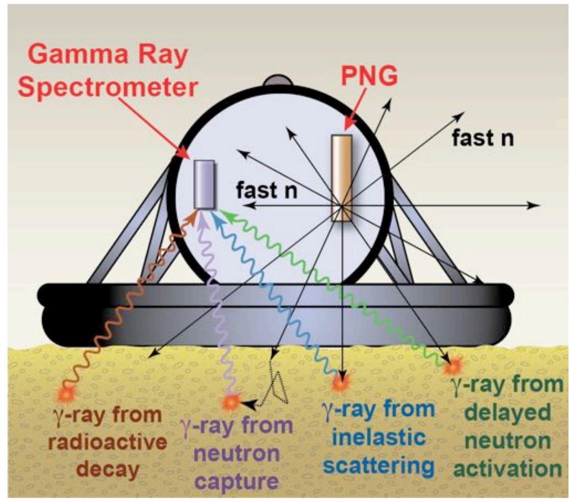

Figure 1. PING's PNG excites the nuclei in the surface material resulting in the emission of characteristic gamma rays. The detection of these gamma rays by the GRS yields the elemental composition.

thus analyzed to determine the complete elemental composition from the spectral signature of individual elements.

PING's PNG and GRS system is based on Schlumberger Technology Corporation's Litho Scanner instrument used extensively in the oil industry for determining the elemental composition of material down oil well boreholes[3]. Schlumberger has over three decades of experience measuring the rock composition down oil wells. This technology is easily adapted to space applications since the oil well environment is similarly harsh. Thus the Litho Scanner is able to withstand up to 1000 g's shock and operate in the -20 C to 175 C temperature range. In the oil well configuration, the cylindrical PNG and GRS are co-aligned. Adapting the Litho Scanner to the PING Venus application just requires the PNG and GRS to be placed separately within the Venus probe volume as shown schematically in Figure 1. There is significant flexibility in the orientation and placement of the PNG and GRS and instrumental electronics within the lander pressure vessel. Monte Carlo simulations will be employed to optimize the location of the separate components.

Operational Advantages and Capabilities: A pulsed neutron generator is required on the surface of Venus since galactic cosmic rays will not penetrate the dense Venusian atmosphere. A deuterium-tritium (D-

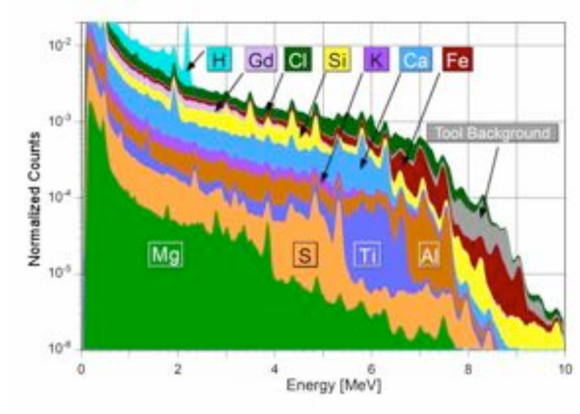

Figure 2. This thermal neutron capture spectrum is shown as the sum of individual elements' spectral contributions.

T) PNG has multiple advantages over radioactive sources since its higher (14 MeV) neutron energy allows the measurement of a wider variety of elements. Another distinct advantage is that the PNG can be turned off so that it will not be irradiating the rest of the science payload during the cruise phase of the mission. During operation, the total radiation dose to the rest of the probe instrumentation is small. NASA's experience using the Dynamic Albedo of Neutrons (DAN) instrument on the Mars Science Laboratory [4] has shown that a D-T PNG will not adversely affect the other instruments in the Venus probe. The ability to turn off the PNG neutrons will also allow the GRS to measure the gamma rays produced by activation as well as the naturally radioactive elements K, U, and Th.

The combination of a PNG with an average isotropic intensity of 1-5×10^8 neutrons per second with the unusually fast light decay time (16 ns) of the $LaBr_3$ scintillator GRS allows for count rates in excess of 2 MHz. This extremely high gamma ray throughput is necessary to provide the counting statistics needed for the short (approximately one hour) measurement times currently available for Venus landers. $LaBr_3$ has an internal gamma ray background that can be measured with great precision and has an intensity sufficiently low that the PNG neutron-induced gamma ray emission is not significantly affected. While this background does reduce the precision of measurements of the naturally occurring elements K, U, Th that are made with the PNG off, our computer simulations have shown that $LaBr_3$ nonetheless has high precision for K, U, and Th measurements. Preliminary results indicate that a K abundance measurement is achievable with a 2% relative uncertainty. These simulations and their results will be fully described in this presentation.

Gamma Ray Data Analysis: The 3% FWHM energy resolution at 662 keV for $LaBr_3$ is better suited to full spectrum analysis rather than peak fitting analysis. Full spectrum analysis makes use of every count in the measured spectrum rather than just the counts in the energy peak and thus can produce results with high statistical precision without requiring the excellent energy resolution of a high purity germanium detector. Gamma-ray spectra are decomposed into the spectral responses of individual elements as determined by calibration tests on Earth. Figure 2 illustrates how individual element spectral signatures add up to produce the recorded spectral data.

Fitting the entire GRS gamma-ray spectrum to a linear combination of these individual element shapes produces high precision elemental composition information. The individual elements' contribution to the total spectrum, the spectral yield, is used to determine the abundance of each element using the closure method where the sum of spectral yields, normalized to each element's sensitivity, is set equal to unity. Model results using the Monte Carlo N-Particle (MCNP6) [5] radiation transport code for various configurations of PING inside a Venus lander pressure vessel demonstrate the precision and accuracy of Venus elemental composition measurements possible with PING in the brief time available on the planet's surface.

Gamma ray Neutron Test Site: These computer simulation results are supported by experimental measurements at the gamma ray - neutron instrument test facility near NASA Goddard Space Flight Center [6,7]. This test facility is located 3.8 miles from the NASA Goddard main campus and provides the capability to safely run a deuterium-tritium neutron generator. The gamma ray–neutron test facility consists of two large (1.8 m x 1.8 m x .9 m) Columbia River basalt and Concord Gray granite test monuments located in the middle of an open field and surrounded by a 50-meter radius radiation safety perimeter. The complete bulk elemental composition of both basalt and granite has been independently measured to ppm levels so that they act as measurement standards for our tests. 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.

References: [1] Surkov, Y., *et al.,* (1984), *Geophys. Res. Suppl*., 88:481-493.; [2] Surkov, Y. *et al.,* (1986), *Geophys. Res. Suppl.,* 91:215-218.; [3] Stoller, C. *et al.,* (2011), *IEEE NSS/MIC Conference Proceedings*, pp. 191-195.; [4] Mitrofanov, I. *et al.,* (2012) *Space Sci. Rev.,* 170: 559-582; [5] Pelowitz, D.B. (Ed.), (2013). Monte Carlo N-Particle-6 (MCNP6) User's Manual Version 1.0. Report LA-CP-13-00634, Rev. 0, LANL; [6] Parsons, A. M. *et al*. (2011) *NIM-A*, 652:674–679.; [7] Bodnarik *et al.,* (2010), LPSC 2581.