MEASURING VENUS' BULK ELEMENTAL COMPOSITION WITH BECA

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Introduction: The Bulk Elemental Composition Analyzer (BECA) instrument 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 (up to 30 cm depth and similar lateral distribution). These data are vital for understanding Venus, as little is currently known about the bulk composition of its surface. 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, BECA provides a significant improvement over previous Venus bulk composition studies.

Bulk elemental composition measurements of the subsurface of Venus are challenging because of the extreme surface environment (462 ˚C, 93 bars pressure). The instruments included on landed probes of the surface of Venus must therefore be enclosed in a pressure vessel. The high surface temperatures require a thermal control system that can keep the instrumentation and communication electronics within their operating temperature range for as long as possible. Currently, Venus surface probes can operate for only a few hours. It is therefore crucial that the lander instrumentation be able to make statistically significant measurements in a short time.

BECA is well suited for Venus surface measurements since it will be located completely inside the Venus lander. BECA has no moving parts and because neutrons and gamma rays can penetrate the pressure vessel walls, BECA does not require a pressure vessel window or any sample manipulation, a valuable attribute given the difficulties associated with operating external mechanisms and sample handling systems in the harsh Venusian surface environment.

Instrument Description: BECA consists of a Pulsed Neutron Generator (PNG) and a Gamma-Ray Spectrometer (GRS), as shown in Figure 1. The PNG emits isotropic pulses of 14.1 MeV neutrons that penetrate the pressure vessel walls, the dense atmosphere and Venus' surface. Nuclear reactions occur between these incident energetic neutrons and Venus's subsurface material to 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 intensities provide 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 BECA's cerium bromide ($CeBr_3$) scintillator GRS. The GRS spectra are analyzed to determine the Venus elemental composition from the spectral signature of individual major, minor, and trace radioactive elements in the surface to a depth of tens of cm.

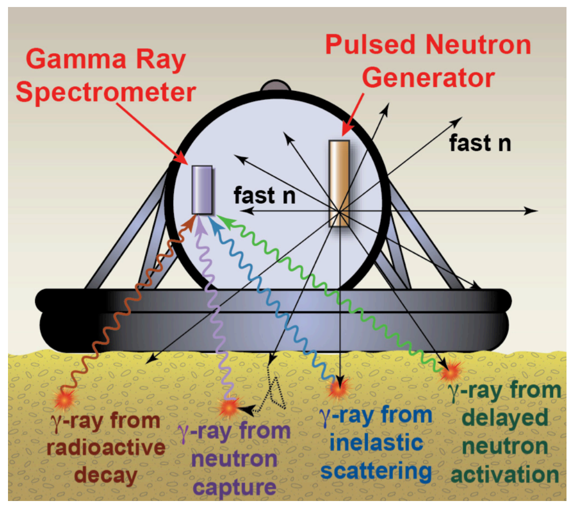

Figure 1. BECA's PNG excites the nuclei in the surface material resulting in the emission of characteristic gamma rays. The detection of these gamma rays by the GRS yields the elemental composition.

BECA's PNG and GRS system is based on Schlumberger Technology Corporation's Litho Scanner* instrument, which is used extensively in the oil industry for determining the elemental composition of material down oil well boreholes [3]. The Litho Scanner is very similar to BECA except that its GRS uses $LaBr_3$ instead of $CeBr_3$. $CeBr_3$ is expected to have the same performance when used with the PNG, but will provide superior measurements of naturally radioactive elements due to its lack of internal background. The Litho Scanner technology is easily adapted to space applications since the oil well environment is similarly harsh. In the oil well configuration, the cylindrical PNG and GRS are co-aligned. Adapting the Litho Scanner to the BECA Venus application requires the

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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 components.

Operational Advantages and Capabilities: A neutron source is required on the surface of Venus because galactic cosmic rays do not penetrate the dense Venusian atmosphere. A deuterium-tritium PNG has multiple advantages over radioactive sources since its higher (14.1 MeV) neutron energy allows the measurement of a wider variety of elements and this neutron source can be turned off during the launch and cruise phase of the mission.

The combination of a PNG with an average isotropic intensity of up to 5×10^8 neutrons per second with the unusually fast light decay time (< 20 ns) of the $CeBr_3$ scintillator GRS allows for count rates of many hundreds of kHz, depending on BECA's distance to the Venus surface. This high gamma ray throughput is necessary to provide the counting statistics needed for the short (~ 1 hour) measurement times currently available for Venus landers.

Test Results: On July 6 and 7, 2016, a Schlumberger Litho Scanner oil well logging tool was used in a series of experiments performed at the Gamma Ray Neutron Test (GNT) facility [4] at NASA's Goddard Space Flight Center. The Litho Scanner tool was mounted above large (1.8 m x 1.8 m x .9 m) granite and basalt monuments and made a series of one-hour elemental composition measurements to demonstrate the successful operation of a BECA prototype in a planar geometry more similar to a planetary lander measurement.

Measurements were made in various configurations to determine how the BECA prototype performance scales with 1) the height of the instrument above the monument, 2) differences in elemental composition between the granite and the basalt as well as additional Ti and S added to the configurations and 3) different thicknesses of polyethylene placed on top of the monuments to represent varying amounts of phase-change material that would be used inside a Venus lander. These tests also provide an experimental benchmark for our Monte Carlo simulations that will be used to determine the elemental measurement precision in an actual Venus probe configuration.

Knowing the independently measured elemental compositions of our basalt and granite monuments from an assay provided by an outside laboratory allows us to quantitatively compare these measurement results with the actual elemental concentrations present in each monument. Some key systematic effects for which this measurement has not been optimized include: the elemental standard spectra have been derived for the fluid-filled oil-well borehole environment, not open-air monuments; and the mineralogical assumptions that inform the conversion of spectral yields to elemental concentrations were designed for sedimentary rocks, not granite or basalt.

Table 1: Preliminary Granite Test Results

Element	Units	Granite Assay	Granite BECA Results
Al	wt%	7.40	7.41
Ca	wt%	0.63	0.74
Fe	wt%	1.14	1.23
Gd	wt-ppm	4.55	4.72
K	wt%	4.32	5.09
Mg	wt%	0.17	0.11
Mn	wt%	0.04	0.04
Na	wt%	2.27	2.09
Si	wt%	34.23	34.65
S	wt%	0.01	0.00
Ti	wt%	0.14	0.18

Table 1 shows preliminary results for one of our measurements of the granite elemental composition. These one-hour measurements were made with an average isotropic PNG neutron output of 3.8×10^8 neutrons/s and with the PNG and $LaBr_3$ GRS of the Schlumberger Litho Scanner tool located 20 cm above a 2.54 cm thick layer of polyethylene placed on top of the bare granite monument. An identical measurement was performed on the basalt monument.

While the absolute statistical uncertainties for the results above were typically less than 0.1 wt%, the overall measurement uncertainties are dominated by a number of systematic effects. We will present the test results for the measured basalt and granite monuments in various configurations and will describe the systematic effects that drive up the measurement uncertainties.

References:

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