**ADDRESSING HIGH-PRIORITY VENUS SCIENCE OBJECTIVES WITH ORBITAL AND SURFACE-BASED NUCLEAR SPECTROSCOPY.**
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**Introduction:** Nuclear spectroscopy is a proven technique for measuring the elemental composition of planetary surfaces, including Venus [1]. The technique has also been used to characterize the composition and time variability of planetary atmospheres [2-4]. We explore the use of nuclear spectroscopy experiments at Venus to address important questions as identified in the VEXAG "Goals, Objectives, and Investigations for Venus Exploration" report (VEXAG/GOI) [5].

**Orbital Measurements – Lightning Monitoring:** Lightning is an important dynamical process in atmospheres, and determiming the frequency, time-, and spatial-dependence of lightning on Venus is an important goal (VEXAG/GOI Objective I.C-3). Earth-orbiting gamma-ray observatories have mapped lightning across the surface of the Earth by detecting electron-induced Bremsstrahlung gamma-rays produced within the Earth's atmosphere [e.g. 6]. A gamma-ray detector on a low-altitude (<2 Venus radii) Venus orbiter would likewise provide real-time monitoring to search for similar lightning-induced gamma rays at Venus [7].

**Orbital Measurements – Atmosphere Composition and Volcanic Gas Monitoring:** Neutron spectroscopy is sensitive to the abundances of neutron moderating (e.g. H, C, N, O) and absorbing (e.g. Ar, S, Cl, H) elements. A MESSENGER- or Lunar Prospector heritage Neutron Spectrometer (NS) on a low-altitude Venus-orbiting spacecraft can be used to derive the bulk abundances of neutron moderating and absorbing elements within the atmosphere at altitudes >60 km. This capability supports two measurements:

*1) Derivation of the nitrogen content of the upper atmosphere*. Despite being the second-most-abundant compound in Venus' atmosphere, the volume mixing ratio for $N_2$ is unknown by 45% [8]. Knowledge of the N content of Venus' astmosphere is crucial for understanding the divergent evolutions of the atmospheres of Venus, Earth, and Mars [9] – a high priority investigation for Venus (VEXAG/GOI Objective II.A). Neutron fluxes measured by a Venus-orbiting NS, combined with constraints on the atmospheric composition from prior in-situ experiments [e.g. 8] will provide a precise (<5% uncertainty) determination of the N content of the upper (alt >60 km) atmosphere.

*2) Monitoring volcanic gas concentrations*. Identifying the mechanism(s) by which Venus is releasing its internal heat is a high-priority investigation (VEXAG/GOI Objective II.A, III.B). There is tantalizing evidence for ongoing volcanic activity on the surface, including from long-term monitoring (1978-1996, 2006-2012) of the $SO_2$ content of Venus' atmosphere [10-12]. That data shows variability that may be associated with periodic eruptive events that injecting volcanic gas into the upper atmosphere. A Venus-orbiting NS would provide a time-series measurement that is highly sensitive to the bulk concentration of thermal neutron absorbing elements (Ar, S, Cl, and H), which are all expected to be byproducts of volcanic activity. Similarly, an orbiting GRS can directly track elemental abundances of key elements, as demonstrated on Mars via Mars Odyssey GRS measurements of seasonal varying Ar concentrations at polar latitudes [3]. Both techniques provide time-series measurements of key elements associated with volcanic activity as injected into the upper atmosphere, a crucial constraint on the frequency of present-day volcanic activitity on Venus.

**Surface Measurements:** Knowledge of the nature and composition of Venus' crust is vital to undertsanding how the planet differentiated and evolved over time (VEXAG/GOI Objective II.B). Passive gamma-ray measurements on the surface have the capability to measure the abundances of radioactive elements (K, Th, U), which can be used to distinguish between basalts and more differentiated (Si-rich) material. This type of investigation was successfully carried out by the Venera and Vega landers [e.g. 1], and advances in GRS systems since then can provide significantly improved elemental composition measurements. If paired with an active or passive neutron source, major element abundances (e.g. O, Si, Fe) could also be obtained with <24 hours of operation on the surface.

**Summary:** Low-resource nuclear spectroscopy instrumentation provides high heritage solutions for addressing many outstanding issues in Venus exploration.

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