Considerations for the operation of a ^{3}He proportional counter in the Ganymede radiation environment.

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Introduction: Neutron spectroscopy has the capability to map and characterize water ice deposits on the surface of Ganymede, a primary science goal for the Jupiter Ganymede Orbiter (JGO). The challenge to carrying out neutron spectroscopy at Ganymede is understanding and compensating for the detrimental effects of the intense charged particle radiation environment. Simulations of the response of a Lunar Prospector (LP) style neutron spectrometer (NS) in several radiation environments have been carried out. Where possible, the simulations were benchmarked to in-flight data. Instrument performance during the nominal JGO orbit around Ganymede is simulated using the known charged particle environment. The results of these simulations are used to identify modifications required for an instrument to operate on the JGO as well as to quantify its expected performance.

Neutron Spectroscopy for Planetary Geochemistry: Neutron spectroscopy is a demonstrated tool for the study of planetary surface composition, where it can identify the presence of neutron absorbing elements (such as Fe and Ti) as well as neutron moderators (such as H) on the surfaces of airless or nearly airless worlds. The LP mission demonstrated the capability of neutron spectroscopy to identify water ice deposits in lunar polar regions [1], as well as map the abundance of neutron absorbing elements over the entire surface [2]. A neutron spectrometer on Mars Odyssey was used to map Martian surface hydrogen and CO_2 variations [3,4]. Neutron spectrometers are currently en-route to Mercury [5] and the asteroids 4 Vesta and 1 Ceres [6]. The next frontier for neutron spectroscopy is to study the surface composition of outer solar systems bodies such as Ganymede, where it can be used to map the location, abundance, and depth of elemental H.

Radiation Induced Background: A number of different types of neutron detectors exist; however, the extensive spaceflight heritage and inherent radiation tolerance of ^{3}He proportional counters make them the optimal choice for an instrument operating in the radiation environment around Ganymede. For this study, the ^{3}He proportional counters used by LP serve as the basis for modeling the background signal. The LP NS measured changes in the epithermal neutron flux emanating from the lunar surface, changes which are highly correlated to hydrogen abundance. These changes are observed via the 764 keV ^{3}He neutron capture peak, a signal which was 20 times larger than the nominal background for the detector.

On April 20th, 1998 a class M solar flare caused an increase in the charged particle radiation environment around the Moon. During this event, the background in the LP NS increased by three orders of magnitude, obscuring the neutron signal. This increase was caused by the high proton flux in the detector associated with the solar energetic particle (SEP) event. Comparisons of the SEP proton flux to the known charged particle environment around Ganymede, as measured by the Galileo Energetic Particle Detector (GEPD) [7], reveal that the two proton environments were very similar in magnitude and energy dependence. Therefore, understanding the signal in the LP NS during this SEP event will shed light on the operation of a similar instrument around Ganymede.

Simulations of the NS backgrounds, carried out using radiation transport codes, were compared to the nominal and SEP LP backgrounds. In the energy range around the 764 keV neutron capture peak (500 to 1000 keV), the simulations agree with observations to 10%. Extending these simulations to the Ganymede radiation environment, compensating for the differences between the JGO and LP orbital altitudes and increased size of Ganymede relative to the Moon, we predict a signal-to-background of 2:100. Compared to the LP NS signal-to-background during nominal operations of 20:1, the simulated background is three orders of magnitude larger for an equivalent instrument operating around Ganymede.

Radiation Shielding: Simulations of various radiation shielding schemes were carried out, using different materials and thicknesses. It was found that by replacing the LP aluminum housing around a single LP-style ^{3}He proportional counter with three kg of stainless steel would be sufficient to lower the background by three orders of magnitude. This shielding will not have an effect on the signal, as the neutrons will rarely interact with the stainless steel. The resulting signal-to-noise matches the 20:1 factor for the LP NS. This does not take into account the increased signal which results from the larger high energy proton flux incident on the surface of Ganymede as compared to the moon, an effect which is expected to raise the signal by at least one order of magnitude, but has not yet been quantified. Figure 1 shows the background continuum before and after radiation shielding is added, with the 764 keV neutron capture peak as measured by LP shown for comparison.

Instrument Performance: Using Ganymede geologic maps derived from Voyager and Galileo observations [8], and making assumptions about the water equivalent hydrogen (WEH) abundances for the varying geologic units (Figure 2), a simulated neutron map of Ganymede for the JGO mission has been created (Figure 3). This map calculated the neutron flux in the proposed JGO detector by propagating the surface neutron flux to the detector using the baseline JGO orbital mission parameters (180 days, altitude 400 km). This calculation assumes a signal-to-background of 20:1, which this study suggests is achievable with radiation shielding. The calculation assumed a similar neutron flux to the Moon, neglecting the higher signal expected at Ganymede. Geologic units are clearly discernible in the map, as are the relative WEH abundances.

Conclusions: With the addition of three kilograms of stainless steel shielding to each ^{3}He proportional counter, the Lunar Prospector neutron spectrometer will be capable of mapping the surface hydrogen on Ganymede if included on the JGO mission. Such an instrument would provide unique information about the location, depth, and composition of the water-ice units on the surface. The location and abundances of neutron absorbing elements such as Fe and Ti can also be determined using a JGO NS.

References: [1] Feldman, W.C., et al. (1998) *Science* 281,1496-1500. [2] Lawrence, D.J., et al. (2002) *J. Geophys. Res., 107* [3] Feldman, W. C,. et al. (2002) *Science 207* 75-78. [4] Prettyman, T. H., et al. (2004), *J. Geophys. Res.*, 10.1029/2003JE002139. [5] Goldsten, J. O., et al. (2007) *Space Sci Rev 131*, 339-391. [6] Prettyman, T.H., et al. (2003) *Trans. On Nuc. Sci. 50*, 1190-1197. [7] Mauk, B.H., et al. (2004) *J. Geophys. Res. 109* A109S12 [8] Patterson, G. W., et al. (2003) *Icarus 207* 845-867

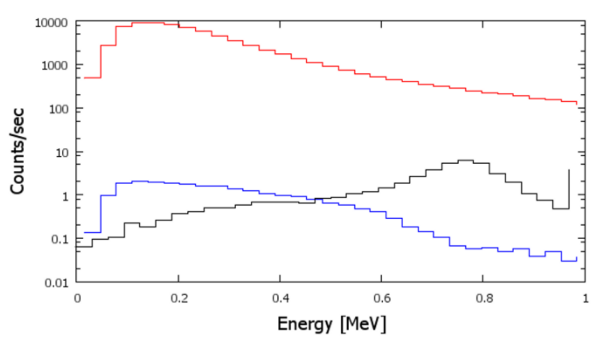

Figure 1. Background in a Lunar Prospector style neutron spectrometer in the Ganymede radiation environment. The red data is the background without radiation shielding. The blue curve includes three kilograms of stainless steel shielding, and is sufficient to reduce the background three orders of magnitude. The black line shows the neutron capture peak for the Lunar Prospector mission. The signal-to-background with the radiation shielding is 20:1, sufficient to map the neutron flux, and thus quantify the hydrogen abundance, on the surface of Ganymede.

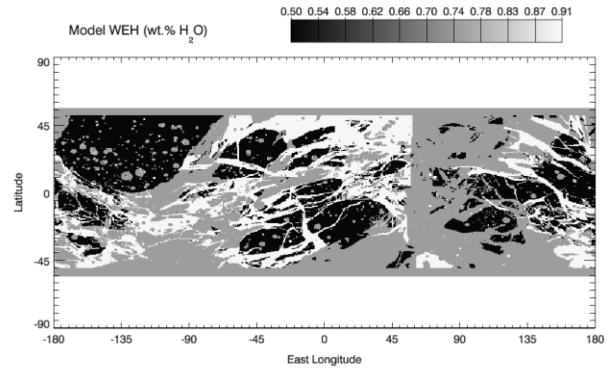

Figure 2. Assumed water-ice abundances for geologic units on Ganymede, using the map of [7]. Bright regions have been assigned a water equivalent hydrogen (WEH) abundance of 90 wt%, dark regions have WEH of 50 wt%, and all other regions have an intermediate WEH value of 75 wt%.

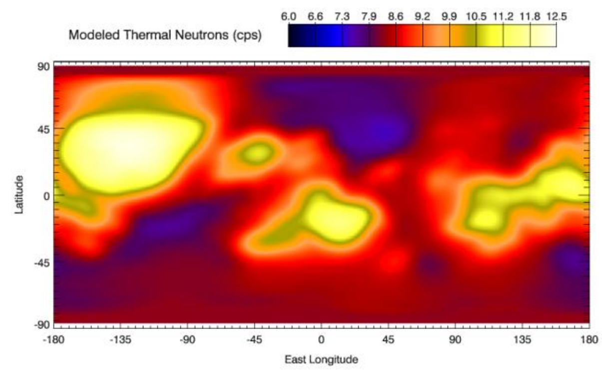

Figure 3. Simulated neutron flux map for the nominal Jupiter Ganymede Orbiter mission carrying a Lunar Prospector style neutron spectrometer and assuming the composition detailed in Figure 2. Geologic units, along with the corresponding water ice abundances, are clearly visible. Neutron spectroscopy samples the composition at a composition dependent depth, which will vary from cm's to m's, therefore the proposed instrument would also contain depth profile information not obtained by any other instrument proposed for JGO.