IN SITU NEUTRON SPECTROSCOPY ON THE MARTIAN SURFACE: MODELING THE HYDRA INSTRUMENT FOR DIFFERENT MISSION SCENARIOS. D. J. Lawrence, R. C. Elphic, W. C. Feldman, K. R. Moore, T. H. Prettyman, and R. C. Wiens, Los Alamos National Laboratory, Mail Stop D466, Los Alamos, NM 87545 (djlawrence@lanl.gov).

1. Introduction: Planetary neutron spectroscopy has proven to be highly successful in remotely detecting and measuring the abundance of water on planetary surfaces such as Mars and the Moon [1,2]. Because of the central role played by water on Mars and the need to make in situ measurements of water abundances for landed missions, neutron spectroscopy is also being investigated as a technique for quickly determining the near-surface water abundance for future Mars missions, such as the Mars Smart Lander (MSL) [3,4,5].

We are currently developing a water- and hydrate-sensing instrument called "HYDRA" that is being supported by the NASA Mars Instrument Development Program (MIDP). Previous work has been supported by the NASA Planetary Instrument Design and Development (PIDDP) Program. A detailed description of the science justifications for the HYDRA instrument are given as a companion paper in this conference [5]. Here we focus on summarizing results of modeling work that demonstrates surface based neutron spectroscopy is indeed feasible and can be successfully carried for a wide variety of mission scenarios. In particular, we have investigated 1) the effects of mounting a neutron spectrometer (NS) on the body of a rover and/or lander; and 2) the effects of making neutron measurements in the presence of a radioactive thermal generator (RTG) that produces copious amounts of neutrons. In both of these situations, we have determined that robust measurements of water content can be made using the technique of neutron spectroscopy.

2. Instrument Modeling The most straightforward way to make neutron measurements on the Martian surface is to use ^{3}He neutron detectors. These detectors are proportional counters filled with ^{3}He gas that has a high probability for absorbing neutrons. Advantages of ^{3}He detectors include a large efficiency for detecting neutrons, low mass (^{3}He sensors can be made for <100g), ruggedness (^{3}He sensors have survived shocks of up to 1500g's), and extensive spaceflight heritage on NASA and Department of Energy based missions. Figure 1 shows a possible configuration of how a HYDRA instrument might be implemented. The configuration includes two ^{3}He tubes where one is covered in a layer of Sn and the other is covered in a layer of Cd. As with the Lunar Prospector NS [6], the Cd covered tube measures epithermal neutrons and the Sn covered tube measures both thermal and epithermal neutrons. Thermal neutron measurements are obtained by subtracting the Cd counting rates from the Sn counting rates.

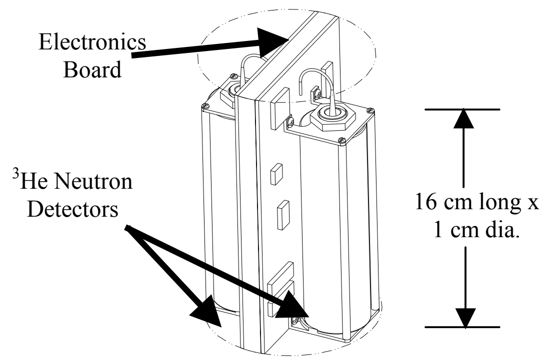

Figure 1: Schematic diagram of a rover based neutron detector.

Because HYDRA can be implemented on a variety of platforms (lander, rover, penetrator, borehole), the configuration of Figure 1 is only a template used for modeling purposes. The exact geometry of a particular instrument can be configured to the given application. We expect that a HYDRA instrument of the type shown in Figure 1 can be built having a mass of 500 g, power draw of 500 mW to 1W, and a data rate of ~1 bit per second.

For all portions of this study, we modeled the NS and its environment using the Monte Carlo code MCNPX [7]. MCNPX is being used extensively for the analysis of Mars Odyssey gamma-ray and neutron data [1,8].

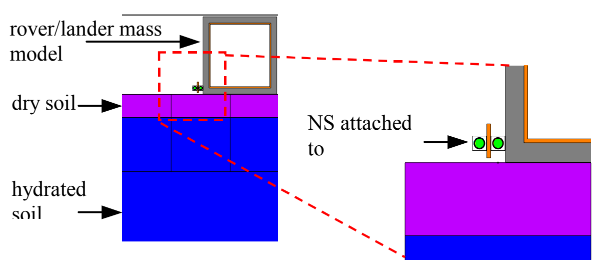

Figure 2: Drawing of the NS and environment used for the modeling of this study.

Figure 2 shows a drawing of the NS and surrounding environment used for this study. The NS shown in Figure 1 is mounted on a simplified rover/lander having a mass of 150 kg and is an approximation of the MER design [9]. For simplification, we have modeled the rover/lander mass as a (50 cm)^3 cube made of 90% aluminum and 10% computer board material. The computer board material is assumed to be 60% fiberglass and 40% epoxy. For the Martian surface, we have assumed a two-layer stratigraphy such that the top dry layer has a Pathfinder-type composition [10] and the semi-infinite bottom layer has the same soil composition with increasing admixtures of H_2O. Finally, we have modeled the Martian atmosphere as having a composition of 70.63 wt.% O, 26.48 wt.% C, 2.89 wt.% N, and a column thickness of 16 g/cm^2.

3. Modeling a NS on a rover/lander platform While the technique of planetary neutron spectroscopy is sufficiently well-developed to make robust measurements of water content from orbit, basic studies still need to be done to understand how well in situ neutron spectroscopy measurements can be made on the Mars surface. Issues we have studied include: 1) It is likely that any rover-based neutron detector will have to be mounted directly on the rover and/or lander. What is the effect of the rover/lander material, including hydrogen, on the hydrogen detection capabilities of a neutron detector? Will this material degrade the hydrogen detection capabilities of a rover based-neutron detector? 2) What is the expected counting rate for a in situ neutron spectrometer? 3) What is the influence of the Martian atmosphere on the hydrogen detection capabilities of a neutron detector system?

Figure 3 shows modeling results for bare ^{3}He tubes on the surface and ^{3}He tubes attached to a rover when the surface is bombarded by energetic galactic cosmic rays. Figure 3a shows the epithermal neutron counting rate for varying amounts of H_2O in soil buried under a 15 cm thick dry soil layer. As shown, epithermal neutrons are a strong indicator of H_2O content such that increasing amounts of H_2O show a lower epithermal neutron counting rate. Furthermore, the rover mounted tubes show a higher counting rate than bare tubes. For the most part, this is the result of neutrons from the surface being scattered and moderated by the rover material. Finally, compared to earlier results with no atmosphere [3], the absolute counting rates are a factor of 2 – 3 higher with an atmosphere than with no atmosphere. The qualitative counting rate profile, however, is very similar between the atmosphere and non-atmosphere cases.

Figure 3b shows the percentage change in counting rates for both the rover and bare tubes compared to a dry soil case. As in the previous study, rover based tubes show somewhat lower sensitivity to H_2O variations, but the variations are nevertheless significant. For example, when the lower layer has an abundance of 10 wt.% H_2O, the rover based counting rate change is only 8% lower than the bare case (71% signal change for a rover tube compared to a 77% signal change for a bare tube). The rover body, therefore, has a small effect on the ability of using neutron spectroscopy to measure H_2O.

Finally, we can estimate the amount of time needed for making high precision measurements with good statistics for rover based tubes. For example, if there is a location with 10 wt.% H_2O underlying 15cm of dry soil, the epithermal neutron counting rate is 2.9 counts per second (c/s). To achieve a counting rate uncertainty of 10% takes 35 seconds (where uncertainty is defined as $1/\sqrt{\text{counts}}$); an uncertainty of 5% is achieved in 2.3 minutes, and an uncertainty of 1% is achieved in 58 minutes. These counting rate times are a function of the size of the ^{3}He tubes and will scale roughly as the volume of the tubes. Therefore, if smaller tubes are used, the required counting times will be correspondingly longer.

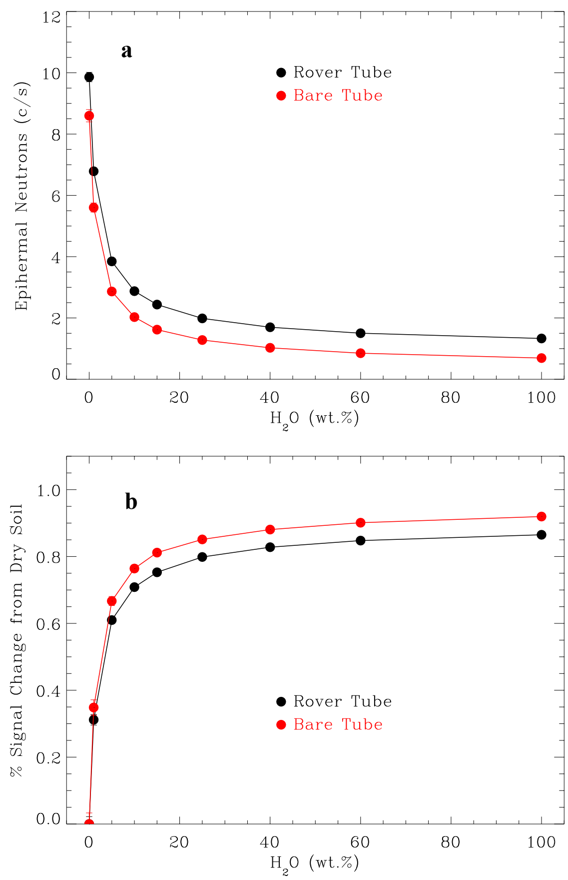

Figure 3: (a) Modeled epithermal neutron counting rates as a function of H_2O for a semi-infinite layer buried underneath 15cm of dry soil; and (b) percentage signal change from dry soil. The black symbols show results for ^{3}He tubes attached to a rover/lander; the red symbols show results for bare ^{3}He tubes on the surface.

4. Modeling an NS in the Presence of an RTG Power Source. In order to extend the surface life of a future rover/lander for the upcoming Mars Smart Lander (MSL), it has been stated that the MSL will be powered with a radioactive thermal generator (RTG) [11]. While such a power source will extend the life of the rover mission, the intense radiation environment of an RTG-based MSL also raises questions regarding the NS measurement technique: 1) Will the background radiation from the RTG's be too intense and overwhelm the NS sensors, thereby preventing a measurement of surface hydrogen content? 2) Conversely, is it possible to use the RTG radiation as a source that enables the measurement of the surface hydrogen content?

In order to answer these questions, we have modeled the NS and rover/lander environment in the presence of a Cassini-like RTG power source, which is being considered for the MSL mission [12]. Figure 4 shows the energy dependent neutron flux emitted from such an RTG. The total energy-integrated flux is 1.2 x 10^{11} n/cm^{-2} s^{-1}. We note that there is also a substantial gamma-ray flux in the vicinity of the RTG. However, we will ignore the gamma-ray component in this study for two reasons: 1) gamma-rays are more easily shielded than neutrons, thereby decreasing their flux at the neutron sensor; 2) ^{3}He neutron sensors are highly insensitive to gamma-rays [13], therefore reducing the effect of gamma-rays on the neutron measurements.

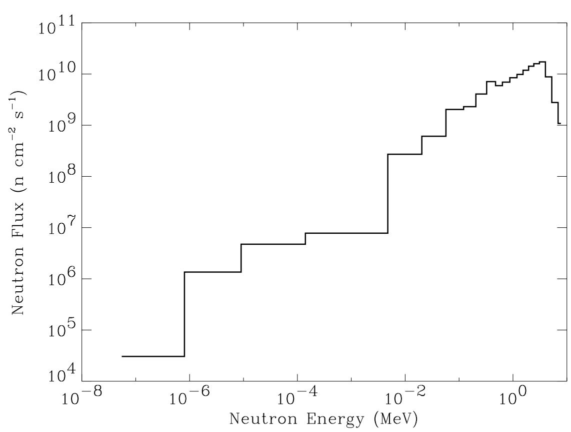

Figure 4: Energy dependent neutron flux that is emitted from a Cassini-like RTG being considered for the MSL mission.

Figure 5 shows the modeling results for thermal versus epithermal neutrons for various H_2O contents and burial depths. Figure 5a shows the results for neutrons produced by galactic cosmic rays (GCR) and Figure 5b shows the results for neutrons produced by an RTG. A number of conclusions from these plots can be made. First, for a given soil composition, H_2O content and burial depth can be determined with thermal and epithermal neutron measurements for both GCR and RTG produced neutrons. However, the counting rate profiles between the two cases are quite different. These differences are mainly due to differences in thermal neutron fluxes (see Figure 6). Finally, the counting rates for RTG produced neutrons are much larger than for GCR produced neutrons. For example, for a soil of 10 wt.% H_2O buried under 15 cm of dry soil, measurements with 1% statistical uncertainty can be obtained in 1 – 2 minutes for RTG produced neutrons compared to ~1 hour for GCR produced neutrons.

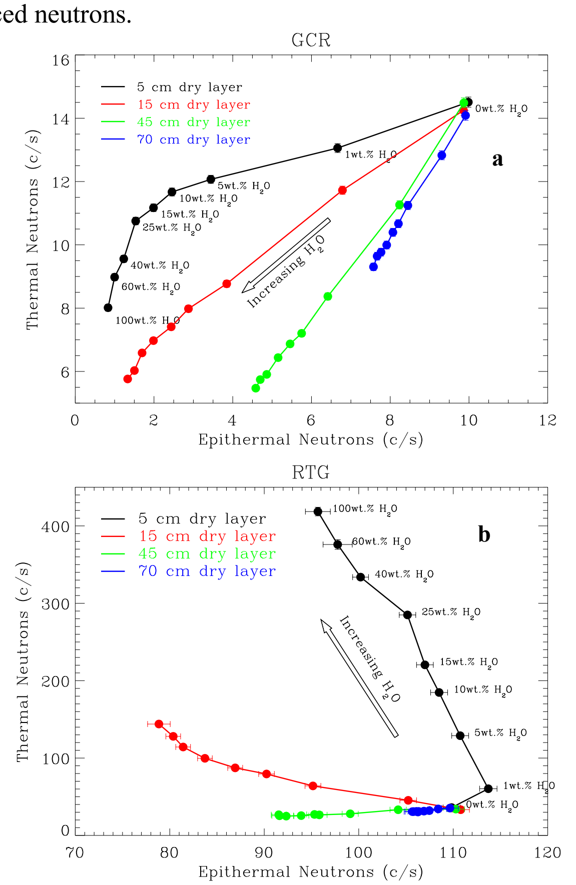

Figure 5: Thermal neutrons versus epithermal neutrons for various H2O contents and burial depths for both (a) cosmic ray and (b) RTG produced neutrons.

Figure 6 gives more detail regarding the differences in counting rate profiles between the GCR and RTG cases. Figure 6a shows thermal neutrons versus H_2O content for GCR produced neutrons with both a thin (15 cm) and thick (70 cm) dry layer. As shown, for both thicknesses, the thermal neutrons show a decrease in the counting rate for increasing H_2O content. In contrast, Figure 6b shows thermal neutrons versus H_2O content for RTG produced neutrons. Here, for a thin layer, there is a strong increase in thermal neutrons versus H_2O content; for a thick layer, there is almost no change in thermal neutrons for increasing H_2O content. RTG produced thermal neutrons are therefore highly sensitive to near surface H_2O. This sensitivity is due to the short penetration depth of RTG primary neutrons compared to cosmic rays, and to the large moderation of primary RTG neutrons to thermal energies from the near surface H_2O.

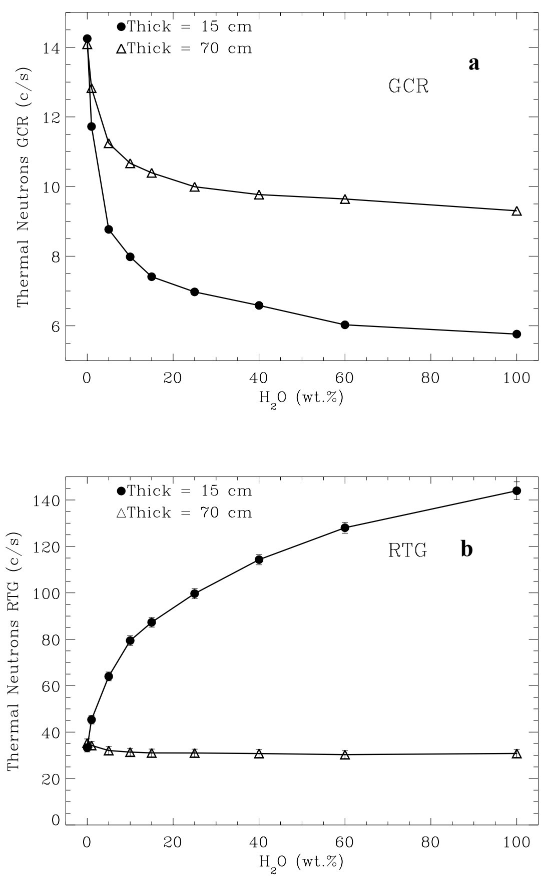

Figure 6: Thermal neutrons versus H_2O content for (a) GCR and (b) RTG produced neutrons.

5. Summary and Conclusions: Based on these modeling studies, we can arrive at a number of conclusions. 1) Mounting a NS on a rover/lander increases the neutron counting rate, but does not dramatically decrease the hydrogen detection sensitivity. 2) Water abundance measurements of moderate precision (5 – 10%) can be made in minutes using only galactic cosmic rays as a source of the neutrons. High precision measurements (<1%) can be made in an hour, again only using cosmic rays as the source of the neutrons. 3) Figure 5a shows that even small amounts of H_2O can be detected even when buried under 70 cm of dry soil. 4) In situ neutron spectroscopy at the surface of Mars is feasible even in the presence of an RTG power source. In fact, RTG-produced neutrons provide a good means of measuring the near-surface H_2O content with high counting rates. These high counting rates increase the operational flexibility for a MSL rover by allowing high-precision (<1% statistical uncertainty) to be made in minutes. 5) RTG produced thermal neutrons enable a very sensitive measurement of near surface (5 –15 cm) H_2O content.

References: [1] Feldman et al., *Science*, 297, 75, 2002; [2] Feldman et al., J. Geophys. Res., 105, E2, 4175, 2000; [3] Lawrence et al., *33rd LPSC*, Abstract #1597, 2002; [4] Lawrence et al., 34th LPSC, Abstract #1763, 2003; [5] Elphic et al., *this conference*, 2003; [6] Feldman et al., *Nuc. Inst. and Meth. A*, 422, 562, 1999; [7] Waters, *MCNPX Users Manual*, LA-UR 02-2607, 2002; [8] Boynton et al., *Science*, 297, 81, 2002; [9] Sevilla, D., JPL, pers. comm., 2002; [10] Bruckner et al., *32nd LPSC*, Abstract #1293, 2001; [11] Hartman, C., NASA Headquarters Briefing, *34th LPSC*, 2003; [12] Jun I., JPL, pers. comm., 2002; [13] Hahn et al., *IEEE Trans. Nuc. Sci*., submitted, 2002.