The Problem of Prompt Gamma Emission for Water Prospecting in Martian Regolith

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INTRODUCTION

The search for life on Mars has driven humanity to a more basic search – for water. Recently cosmic ray induced radiation has been measured from orbiters, and used in combination with modeling to estimate the depth and fraction of water in Martian regolith[1,2,3] A next step in Mars exploration is a rover based measurement using a neutron source, which will provide a stronger signal than the cosmic ray background. The basic structure of Martian regolith models[1,2,3] is a wet layer overlain by a dry layer. We are therefore studying the inverse problem in which an unknown depth d of dry layer lies over a very deep wet layer whose mass fraction f of water is unknown. The task we set is to formulate a problem in which measurements of gamma lines from the soil, induced by 14 MeV neutrons from a rover borne generator and measured by a HPGe detector, can be used to solve for the unknown d and f. In particular, we seek two equations $r_1 = h_1(d, f)$, $r_2 = h_2(d, f)$ in which two photopeak area ratios r_1, r_2 can be used as data to solve for d and f, and the functions $h_1(d, f), h_2(d, f)$ can be evaluated by Monte Carlo for any values of the unknowns d, f. A similar program has recently been carried out for PGNAA of large homogeneous samples.[4,5,6]

THE MODEL

The model comprises of two layers: the top dry layer and the lower wet layer, of effectively infinite depth. The primary question is: can d, f indeed be found by measuring a few gamma lines at a single standoff distance between the neutron source and gamma detector. Put differently, can three gamma lines be found such that the resulting two gamma line ratios r_1, r_2 map one-to-one to d, f.

Modeling was done in MCNP, with Martian regolith been modeled based on the composition and density used in Vincke[7] (based on Viking and Pathfinder measurements). Various wet-layer depths and various water fractions were simulated, with d from 0 to 20 cm in 2 cm increments and from 25 to 60 cm in 5 cm increments, each with f taking values from 15% to 45% with increments of 5% water by mass, using over 130 MCNP runs with 90 million particles each. Uncollided gamma fluxes in select gamma lines were tallied, at standoffs from 2cm to 100cm. From these spectra we examined various possible line ratios, and eliminated those that did not lead to the desired one-to-one relation between r_1, r_2 and d, f. The most promising gamma lines for Martian regolith prospecting were seen to be Si(n,n’), H(n,γ) and Si(n,γ) because the Si lines are seen to be always strong, and together with the H line yield the required one-to-one relationship. It should be noted that the existing H measurements[1,2,3] from Mars rely on the H (n,g) line, along with neutron measurements and normalization to Viking data.

RESULTS

In order to present the one-to-one relation, we used the gamma line ratios H(2222 keV)/Si(1779 keV) and Si(3540 keV)/Si(1779 keV) and plot these ratios for various water fractions at various depths. For instance in Figure 1, with a detector standoff distance of 30 cm, each line has constant water fraction and each mark gives the depth as shown in the legend. For our model these are the depths and fractions for which we calculate the gamma flux ratios specified on the two axes. Thus, this is a four dimensional graph with the two independent variables (depth, d, and water fraction, f) specified in the legend and the dependent variables plotted on the two axis. If we are given a point on the plot specified by the two ratios (a measurement) we can interpolate and find d and f. Not all choices for gamma line ratios would give a one-to-one relationship, but the ratios selected for presentation here do. Figure 2 is another such graph with a standoff distance of 100 cm. While 133 marks are used to generate each plot, only a few are shown to aid the eye without overwhelming it. Monte Carlo uncertainties are less that 1% for all points.

CONCLUSIONS

The problem of finding water layer depth and water fraction can be solved with well chosen gamma line ratios based on Si(n,n’), H(n,g) and Si(n,g), and also a well chosen standoff distance.

In practice a measurement system using HPGe detectors should be able to measure the gamma lines selected, well resolved from their neighbors.[5] But measurement time will be dictated by count rates, background, and the neutron source strength, standoff distance, and other details of the system design. It should be noted that the 2223 H(n,γ) line is not usually the strongest line; the 1779 keV Si(n.n’) is usually strongest. The H line varies greatly depending on water content an depth), so count times will likely be determined by the counts under the H peak. At present we anticipate no problem in resolving this line in practice (and have previously done so[5]), but until real measurements are made this concern must be recognized. It can be seen in Figs. 1 and 2 that depth determination is less sensitive to uncertainty in the line ratios than is water fraction determination. It can also be observed that as the wet layer falls deeper into the regolith, sensitivity to water fraction is lost, but that the larger standoff distance gives greater sensitivity to deep water than does the smaller standoff distance.

Finally, it must be noted that all “water” measurements on Mars rely on using hydrogen as a surrogate for water. This foundation is sound because there is little expectation of large quantities of H in other forms in these planetary regoliths, and other data---minerals formed in water, the presence of frost, of water vapor in the atmosphere, and water ice at the poles---speaks to the past and current presence of water.

In the future we will examine the sensitivity of the solution to other parameters, such as the water content of the top layer, or the to density[6] and composition of the regolith. Proof-of-principle measurements are being considered. Further, while we have established a one-to-one relationship, we would also like to develop an iterative scheme[4] to solve the problem, rather than relying on a database lookup as the figures provide.

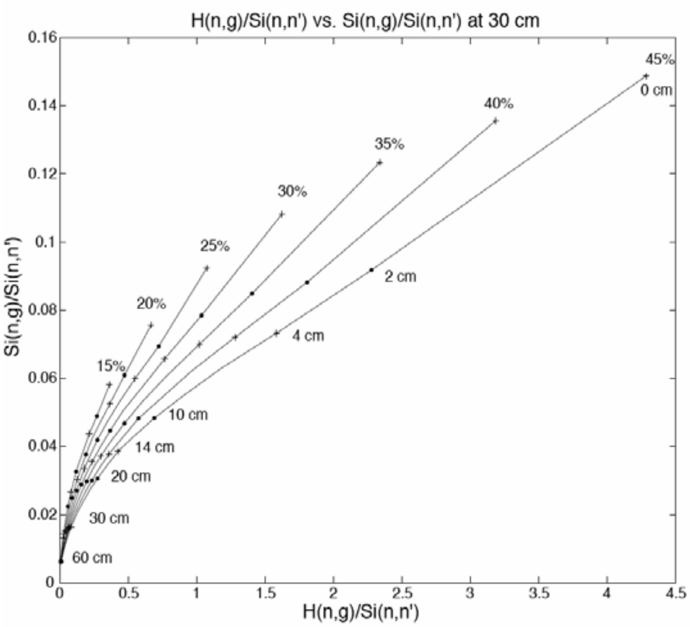

Fig. 1: Gamma line ratios as they would be measured at a standoff distance of 30 cm, and the grid of water layer depth and water fraction. From this plot the depth and water fraction can be found uniquely from the measurement of the gamma line ratios. The relative uncertainty in the location of each mark is less than 1% in all cases.

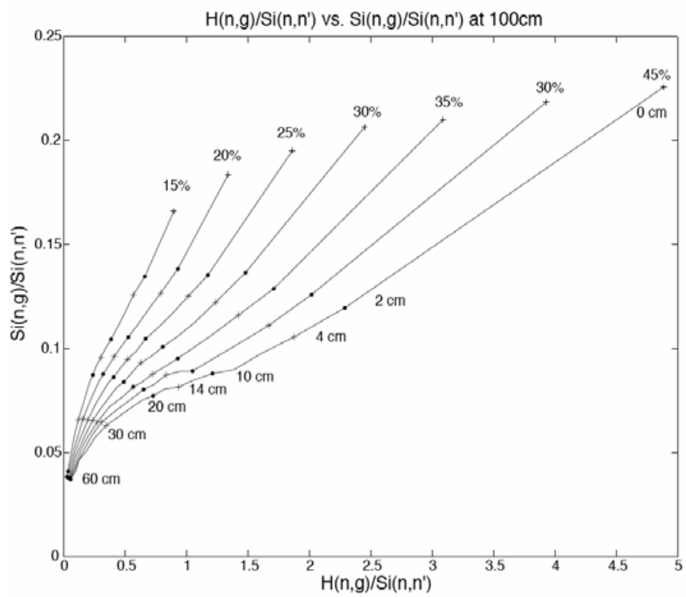

Fig. 2: The gamma line ratios (linear scale) as they would be seen at a standoff of 100 cm, with the grid of water layer depth and water fraction. The relative standard uncertainty in the location of each mark is less than 1% in all cases.

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