INVESTIGATION OF MARTIAN H_2O AND CO_2 VIA GAMMA-RAY SPECTROSCOPY

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Earth-based and spacecraft investigations of Mars have shown that H_2O and CO_2 are the two most important volatile species on the planet. While major advances have been made concerning the evolution and present state of H_2O and CO_2 on Mars, many unanswered questions remain. The upcoming Mars Observer mission will include in its payload a gamma-ray spectrometer. This instrument will measure the spectrum of gamma radiation emitted by the planet. From the measured gamma-ray spectrum, it is possible to infer a considerable amount of compositional information. Particularly, the experiment will enable study of the spatial and temporal distribution of H_2O and CO_2 in the near-surface martian regolith.

The presence of H_2O can be investigated directly by measurement of the 2.223 MeV gamma-ray line of H. Because H is the most important element for moderating the neutrons produced by cosmic-ray interactions with the surface, it can also be investigated by the direct or indirect determination of the fast to thermal ratio of the neutron albedo flux. In general, for materials with high H concentrations, the total neutron flux consists of proportionally more thermal neutrons and the flux peaks at shallower depths than for materials with low H concentrations. The neutron fast/thermal ratio may be determined indirectly from the gamma-ray spectrum. Prompt capture lines result primarily from interactions of nuclei with thermal neutrons, while inelastic scattering lines result primarily from interactions with fast neutrons. Some elements, such as Si and Fe, emit strong lines of both types. One may therefore examine ratios of inelastic scatter to prompt capture line strengths for these elements, and acquire information regarding the H distribution that is similar to what one would acquire directly from fast/thermal neutron ratios. The 2.223 MeV gamma-ray flux is an indicator of the amount of H in the upper few tens of g cm^{-2}, while the inelastic/capture ratio for Si or Fe is related to the amount of H in the upper $\sim$ 100 g cm^{-2} or more. It is therefore possible to obtain information about the vertical distribution of H. CO_2 is more difficult to detect, but it may be possible to determine the thickness of a layer of CO_2 frost by direct detection of C or by inference from attenuation of gamma rays from underlying material.

We wish to determine how effectively questions regarding the distribution of H_2O and CO_2 on Mars may be addressed with orbital gamma-ray data. Our approach is straightforward. We have identified several unanswered questions regarding martian H_2O and CO_2. These include: *(1)* What is the ice/dust ratio of the polar layered deposits? *(2)* What is the thickness of the polar perennial ice? *(3)* What is the thickness of the CO_2 that covers the southern perennial ice? *(4)* What is the thickness of the seasonal CO_2 frost caps? *(5)* How much H_2O is there in the seasonal frost cap? *(6)* How does the distribution of subsurface ice vary with latitude and geologic material? *(7)* What is the degree of hydration of minerals making up the martian surface? *(8)* Are there near-surface liquid water "oases" in Solis Lacus or elsewhere? For each question, we have formulated a simple multi-layer model of the martian surface. In each model, the martian surface is composed of one or two horizontal layers. If one surface layer is present, it is taken to be semi-infinite; if two surface layers are present, the upper one has some variable thickness and the lower one is semi-infinite. A layer may be composed of H_2O, CO_2, or soil with a composition like that at the Viking landing sites, or some homogeneous mixture of two of these materials. In two-layer models in which one layer is a mixture of two materials, the other layer is always composed of a single material. Each model therefore can be completely described by no more than two parameters. As an example, the problem of detection of subsurface ground ice is modeled with a variable-thickness upper layer of pure soil, and a semi-infinite lower layer of intermixed soil and H_2O. In this case, the two parameters are the thickness of the upper layer and the soil/H_2O mass ratio of the lower layer. For each model, we calculate the gamma-ray spectrum that will be observed by a spacecraft in orbit. All of the calculations include atmospheric attenuation and emission. We then examine ways in which the observed spectrum can be interpreted to yield unique determinations of values for the parameters of interest.

In order to predict the expected gamma-ray fluxes from the surface of Mars and the sensitivity of the Mars Observer gamma-ray spectrometer experiment, the neutron spatial and energy distributions in the near-surface materials must be modeled. We use a primary cosmic-ray spectrum and resulting secondary neutron source distribution like that for the Moon. We then calculate the resulting neutron spectrum and distribution for the surface and atmosphere under consideration using the ANISN code. This is a discrete ordinate code that solves the neutron transport equation by evaluating the flux for discrete directions, positions, and energies. The code is one-dimensional, and uses 100 neutron energy groups and 100 spatial intervals with a spacing of 5 g cm^{-1}.

Once the neutron spatial and energy distributions have been determined, we calculate the discrete line gamma-ray fluxes produced by neutron interactions. For capture lines, the calculated thermal flux is used with the appropriate thermal neutron capture cross-sections and gamma-ray yields to calculate the gamma-ray line flux. Inelastic scatter gamma-ray fluxes are calculated in a similar manner with the inelastic scatter cross-sections integrated over energy at each depth. Production of gamma rays by natural radionuclides is also calculated. All gamma-ray line strengths are corrected for attenuation in the martian surface and atmosphere. The gamma-ray background is calculated from the observed lunar background, scaled to Mars from gamma-ray transport results.

Combining line strengths, background strength, detector characteristics, and counting time, we may estimate the quantitative uncertainty of the measurements to be made. For our calculations, we used the area, energy resolution, and efficiency of a laboratory 120-cm^{-3} HPGe detector, and a counting time of 38 hr. This period corresponds to the total integration time for a single gamma-ray spectrometer resolution element (about 300 km diam.) near the poles over one martian year.

We have considered a total of five models:

Model 1: Intermixed Soil and H_2O: This model can be used to address problems such as the ice/dust ratio of the layered deposits, the dust content of the north polar perennial ice, and the degree of hydration of hydrated silicates. Sample results are given in Figure 1, where we plot two observed line strength ratios as a function of the mass fraction of H_2O present. For small amounts of H_2O, optimum results are given by the ratio of Si inelastic capture to prompt capture line strengths, while for larger amounts of H_2O, optimum results are obtained by using the ratio of H (2.223 MeV) to Fe (capture). For a simple model such as this, it should be possible to determine the H_2O content to a high degree of accuracy.

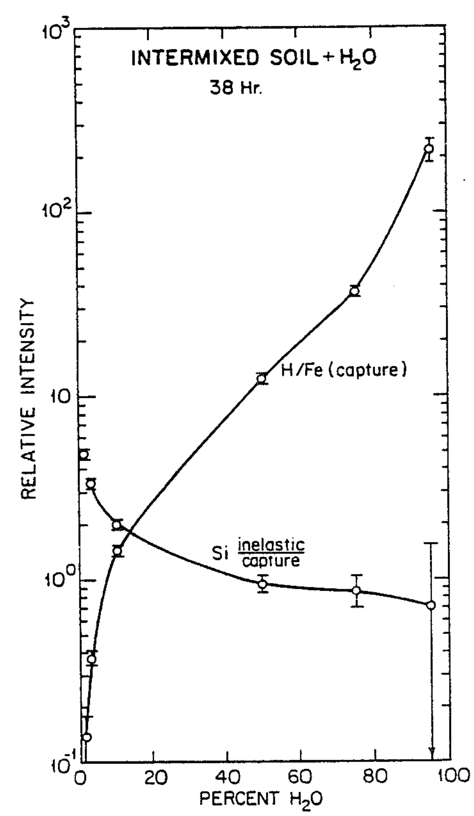
Model 2: Soil over Soil + H_2O: This model consists of two layers: a pure soil layer of variable thickness over a semi-infinite layer of soil + H_2O with a variable H_2O mass fraction. This model can be used to address the distribution, depth, and concentration of ground ice (or liquid). Figure 2 plots Si(inelastic/capture) *vs.* H/Fe(capture). Solid curves are contours of constant H_2O mass fraction in the lower layer, and dashed curves are contours of constant thickness of the upper layer. For data falling in the region where the curves are separated, it will be possible to determine both the thickness of the upper layer and the ice mass fraction of the lower layer.

Model 3: H_2O over Soil + H_2O: This model can be used to address the thickness of the north polar perennial ice, which lies atop the layered deposits. Calculations like those in Figure 2 show that unique solutions are possible, but the uncertainties are large. However, if we assume that we know the ice fraction of the lower layer *a priori*, (as might be possible from an independent measurement of the ice content of exposed layered deposits) determination of the ice layer thickness can be improved very substantially.

Model 4: CO_2 over Soil + H_2O: This model can be used to address two problems. In the extreme of very high H_2O mixing ratio in the lower layer, it can be used to investigate the thickness of the CO_2 layer atop the south polar perennial ice. In the extreme of a very low or zero H_2O mixing ratio in the lower layer, it can be used to address the problem of the thickness of the seasonal CO_2 frost cap. Again, unique solutions are possible, but the uncertainties are large in some cases. However, if we know the H_2O content of the lower layer *a priori* (as would be the case if it were determined when the CO_2 layer was absent), uncertainties again can be very substantially reduced.

Model 5: CO_2 + H_2O over Soil: This model can be used to address the H_2O content of the seasonal frost cap. Unique solutions are found for both adjustable parameters, with small uncertainties.

These results indicate that the Mars Observer gamma-ray spectrometer will be a very powerful tool for investigating the distribution and stratigraphy of volatiles on Mars. It is important to note that the results here do not include the substantial additional information about the neutron energy spectrum that will result from the GRS's neutron mode. With this mode, it should be possible to determine fast/thermal ratios directly, providing an independent check on the gamma-ray results, and increasing the overall certainty in the results.



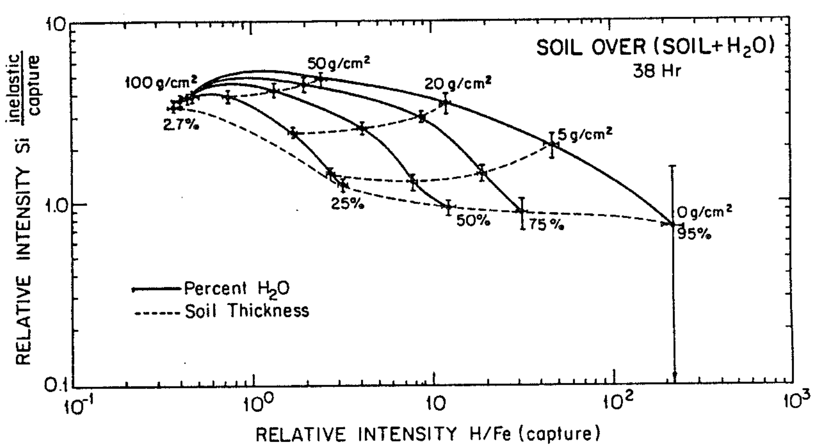


Figure 1 (left)
Figure 2 (above)