GEOCHEMICAL EFFECTS ON NEUTRON DIE-AWAY: IMPLICATIONS FOR THE MARS SCIENCE LABORATORY DYNAMIC ALBEDO OF NEUTRONS EXPERIMENT. C. J. Hardgrove[1] and J. E. Moersch[1], [1]University of Tennessee (1412 Circle Dr., Knoxville, TN 37996, chardgro@utk.edu)

Introduction: The Dynamic Albedo of Neutrons (DAN) experiment on-board the Mars Science Laboratory (MSL) rover *Curiosity* is designed to assess both hydrogen abundance and burial depth as the rover traverses the Martian surface [1]. DAN uses an active type of neutron remote sensing that is new for planetary spacecraft. The technique, called neutron die-away, requires the use of a pulsed neutron generator (PNG) as a supplementary neutron source, as opposed to relying solely on spallation of neutrons in the subsurface by the cosmic ray background.

In neutron remote sensing, low energy (therrmal) neutrons are sensitive not only to hydrogen content, but also to the macroscopic absorption cross section of the near surface materials [3,4,5,6]. We have modeled the effects of varying abundances of all plausible high absorption cross section elements, and present here our results for Cl, which is the most important high macroscopic absorption cross section element on the Martian surface. Mars Exploration Rovers (MER) Spirit and Opportunity found that higher abundances of Cl are commonly associated with locales that have experienced aqueous activity in the past, but where hydrogen-rich materials are not necessarily still present. We show how Cl can strongly influence the profile of thermal neutron die-away curves. Additionally, we show that the timing of thermal neutrons arriving at the detector can be used to discriminate the effects of hydrogen content versus high macroscopic absorption cross section elements on time-integrated neutron count rates. We also model specific geochemical compositions derived from Mars surface measurements made by the MER Alpha Proton X-Ray Spectrometer (APXS) at localities of interest on Mars. Using these examples, we demonstrate that DAN can be used not only to assess the amount of hydrogen in the near-surface, but also to identify other locations with geochemical compositions that may be relevant to the aqueous geologic history of Mars.

Methods: Because there is no analytical model to describe the probabilistic interactions of neutron transport in a variety of geometries, compositions, and energies, we utilize the Monte Carlo Neutral Particle eXtended (MCNPX) code to generate simulated neutron counts and die-away curves for a suite of compositional models [7,8]. To understand the effects of high absorption cross section elements, we model the thermal (low energy, < 0.3 eV) neutron flux as a function of time after a DAN-like, 14.1 MeV PNG pulse for soil compositions that are anomalously rich or poor in these elements. All neutron fluxes are reported at the detector position, 80 cm above the ground, and 1 meter horizontally from the source, to simulate the DAN detector geometry.

To interpret thermal neutron die-away curves quantitatively, we examine both the total neutron flux as well as the timing component of each curve within thermal and epithermal (> 0.3 eV) energy bins. We define the Flux Weighted Time Average (FWTA) as the average arrival time for all thermal neutrons, weighted by the flux at each small time interval of the die-away period. We evaluate the relative changes in thermal and epithermal neutron energy distributions for die-away curves, as well as relative changes to the FWTA for a suite of H_2O and Cl abundances that have been chosen based on actual compositions measured on the Martian surface.

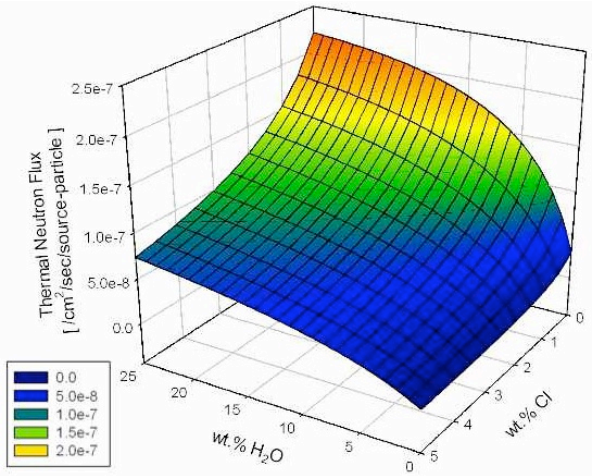

Figure 1: Surface plot showing simulated DAN thermal neutron flux as a function of H_2O and Cl concentration. Legend shows ranges of thermal thermal neutron flux.

Systematically Varying Compositions: To explore a range of plausible values for both H_2O and Cl, we use APXS data acquired from Spirit and Opportunity and vary the abundance of Cl within a generic Mars soil from 0 to 5 wt.% [9]. We also vary H_2O content from 0 to 25 wt.%, based upon Mars Odyssey Neutron Spectrometer data [4].

Site-specific Martian Compsoitions. We also used MER APXS geochemical data from well-studied locations on Mars that are thought to have experienced near-surface aqueous activity in the past. Of this suite of Mars compositions, we present two of the most interesting examples here. These compositions are: 1) Eileen Dean, a Cl-rich soil studied by Spirit in Gusev crater: we use compositional data from Ming et. al,

2008 [9] and model the Eileen Dean soil as a continuous layer 4 cm deep as well as a discrete layer, 4 cm thick and 4 cm deep; and 2) Kenosha Comets, a Si-rich soil found in the Eastern Valley of Gusev crater. Kenosha Comets is a soil devoid of both high scattering and high absorption cross section elements, such that relatively little neutron moderation would be expected. We use the compositional data from Squyres et al., 2008 [10] with soil geometries the same as for Eileen Dean. A depth to these compositions (4 cm) was used in the model geometry, although the exact soil horizon where these compositions appear on Mars was obscured by mixing during the wheel-trenching process; Eileen Dean and Kenosha Comets are cited as appearing at a depth of "at least several centimeters" [9, 10].

Results: The full suite of thermal neutron die-away flux results for H_2O content varying from 0-25 wt.% and Cl content varying from 0-5 wt.% are presented in Fig. 1. These data define a surface that constrains the total thermal neutron fluxes that are possible for given H_2O and Cl contents mixed into generic Mars soil. These results also shows that the amount of Cl in the surface can influence the interpretation of H content if Cl content is not known and correctly taken into account. The total thermal neutron flux from the die-away curve determines the possible range of Cl and H_2O contents. The total thermal neutron flux can be used to constrain the Cl and H2O composition of the soil to fall within a family of anticorrelated abundance values. Then the FWTA value may be used to independently solve for the correct Cl and H2O abundances within this family of values. This is possible because our models also show that high absorption cross section elements (such as Cl) lower the FWTA, whereas the thermalizing element H increases FWTA.

Simulated thermal neutron die-away curves for the Eileen Dean soil and Kenosha Comets compositions are presented in Figures 2 and 3. The reductions in total thermal neutron flux are significant for both the discrete and continuous layers of Eileen Dean and Kenosha Comets composition. For Elieen Dean, thermal neutron flux is reduced by 4% and 33% for discrete and continuous layers, respectively, while FWTA is shifted to earlier times by 1% and 5%. For Kenosha Comets, thermal neutron flux is reduced by 60% and 99% for discrete and continuous layers, respectively, while FWTA is is shifted to earlier times by 34% and 60%. DAN measurements similar to these can be used to identify anomalous locations for further study by other MSL instruments.

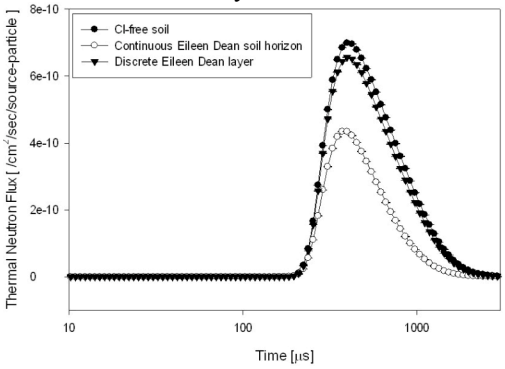

Figure 2: Thermal neutron flux as a function of time after the PNG pulse for dry soil composition, as well as a dry soil composition with a discrete layer and continuous layer of Eileen Dean composition.

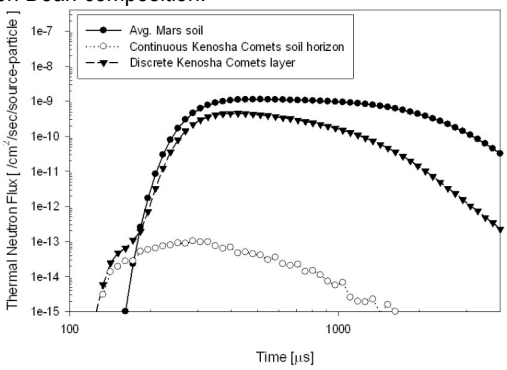

Figure 3: Thermal neutron flux as a function of time after the PNG pules for dry soil composition, as well as a discrete layer and continuous layer of Kenosha Comets composition. Data are presented on a log-log plot in order to show all three thermal die-away curves.

Conclusions: We have demonstrated the effects of high absorption cross section elements on thermal neutron die-away curves similar to those that will be acquired by the DAN instrument on-board MSL. Strong reductions in the total number of thermal neutrons and shifts (to earlier arrival times) in the FWTA along a traverse by MSL may be indicative of hydrothermal Si-rich and evaporitic Cl-rich deposits (Fig. 2 and 3), as well as Fe-rich concretions that result from groundwater percolation (not presented here). Our results show that DAN can not only detect changes in H content, but may also be used to identify possible hydrothermal or evaporitic deposits that are either shallowly buried or at the surface.

References: [1] Litvak et al., (2008) *Astrobio., 8* [2] Busch et al., (2008) *Nucl. Inst. Meth. Phys. A.., 591* [3] Feldman et al., (2000) *Jour. Geophys. Res.,* 105 [4] Feldman et al., (2004) *Jour. Geophys. Res.* 109 [5] Prettyman et al., (2003). *6th Mars, #3253* [6] Prettyman et al., (2004) *Jour. Geophys. Res.* 109 [7] McKinney et al., (2009) *MCNPX Overview, LANL.* [8] Pelowitz et al., (2009) *MCNPX User Manual, 2.5.5* [9] Ming et al., (2008) *Jour. Geophys. Res.* 113 [10] Squyres, et al., (2008) *Science* 320