SIMULATED DAN-ACTIVE MEASUREMENTS USING GEANT4. A. C. Martin[1], J. E. Moersch[1], C. G. Tate[2],

C. Hardgrove[3], I. Jun[4], L. M. Martinez Sierra[4], M. Folsom[5], [1]The University of Tennessee, Earth and Planetary Science Department, , 1621 Cumberland Avenue, 602 Strong Hall, Knoxville TN, 37996, [2]Oak Ridge National Laboratory, Oak Ridge, TN, [3]Arizona State University, School of Earth and Space Exploration, Tempe, AZ, [4]The Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, [5]The University of Tennessee, Department of Nuclear Engineering, Knoxville, TN.

Background: The Dynamic Albedo of Neutrons (DAN) experiment on the Mars Science Laboratory (MSL) rover mission [1] was designed to measure the amount and vertical distribution of hydrogen (H) in the Martian regolith. Subsurface H is useful for understanding the Martian hydrological evolution and provides a window into paleolake conditions in Gale crater [1]. Many regions of Gale crater contain stratigraphic remnants of a lacustrine past [2]. From sol 0 to 298, the MSL rover Curiosity traversed 445 m and descended 18 m into Yellowknife Bay, an outcrop consisting of the Sheepbed, Gillespie Lake, and Glenelg units [3].

DAN is a rover-mounted neutron spectrometer (NS) that has the best spatial resolution of any neutron remote sensing experiment in planetary exploration because it is positioned only ~80 cm from the surface of Mars and is also sensitive to H down to ~50 cm below the surface [4, 5]. DAN includes two ^{3}He proportional detectors, one that records neutrons with energies below ~1keV (Counter of Total Neutrons: CTN), and another that records neutrons with energies between ~0.4 keV and ~1 keV (Counter of Epithermal Neutrons: CETN). The DAN experiment has two modes: passive and active. In active mode, DAN uses a built-in source of high energy neutrons, the Pulsing Neutron Generator (PNG) as a source of high energy (14.1 MeV) neutrons [1]. High energy neutrons are moderated in the subsurface by scattering with regolith nuclei, and can be absorbed by elements with high neutron absorption cross sections such as chlorine (Cl) and iron (Fe) [6]. DAN-passive primarily measures neutrons generated by galactic cosmic ray (GCR) interactions with nuclei in the atmosphere and regolith, as well as the response to fast neutrons produced by spontaneous fission from the Multi Mission Radioisotope Thermoelectric Generator (MMRTG) on MSL [1].

Neutron moderators decrease the energy of fast neutrons. The most effective neutron moderator is H, due to its small atomic mass, which is comparable to the mass of a neutron. However, DAN cannot discriminate between different H host molecules. Therefore, all H abundances are generally discussed in terms of Water Equivalent Hydrogen (WEH), which is defined as the amount of water in weight percent (wt.%) that would exist if all of the H present was bound in H_2O molecules. Neutron absorbers remove neutrons from the system,

thereby decreasing the number of thermal neutrons incident on the detectors. Similar to WEH, the abundance of all neutron absorbers is expressed in terms of Absorption Equivalent Chlorine (AEC) [7], defined as the Cl equivalent of all other thermal neutron absorbers in the regolith. The largest source of variability in neutron absorption on the Martian surface is Cl, due to a large neutron absorption cross section and the wide variability in the abundance of the element on the Martian surface and at depth [6].

The most popular method for analyzing DAN–active data is with Monte Carlo N-Particle (MCNP) or the extended version, MCNPX. MCNP/X was developed at Los Alamos National Laboratory for simulating nuclear processes [8], however this code has fairly restrictive access. Here we show an alternative modeling method, by using Geant4, an open access nuclear transport package designed at CERN [9]. Aside from Geant4 being more modular than MCNP/X, Genat4 has no restrictions that limit its use on a super computer.

Previous Work: From sol 295 to 301, DAN took 18 active-mode measurements in Yellowknife Bay as Curiosity traversed ~15 m over the Sheepbed and Gillespie units [10]. The DAN analysis was done by averaging each subunit and comparing results to simulations. The results indicate that measurements for each subunit are consistent with a 'two-layer model' [10, 11]. A 'two-layer model' is a model that is best approximated with simulations of two horizontal layers with independently varying WEH values in the top 60 cm of Yellowknife Bay regolith [8]. Additionally, the depth to the second layer is allowed to vary in a two-layer model. Currently, there has been a limited geologic interpretation of Yellowknife Bay aimed at explaining the two-layered regolith, and only averaged aggregations of DAN-active measurements from the traverse have been analyzed.

Goals and Hypothesis: The goal of this study is to characterize geological processes that lead to the observed H distribution measured in the regolith of Yellowknife Bay.

Methods: The DAN active measurement is sensitive to the H abundance, neutron absorption cross section and the vertical distribution of those components in a roughly 1 m diameter footprint of regolith [1]. After each pulse from the PNG, DAN measures the neutron flux into 64 logarithmic time bins for both the CTN and

the CETN. The total counts per bin after a single pulse is too low for adequate statistics, therefore each bin is integrated over ~15 min [12]. The shape of the neutron counts per integrated time-bin is known as a 'die-away curve' (Figure 1). By analyzing the shape of a die-away curve, we can determine the H abundance and depth distribution of the regolith directly beneath the rover.

Simulation Methods: With Geant4, simulated neutron die-away curves are produced to mimic DAN-active measurements. Simulations are run for a variety of regolith compositions and geometries. Input parameters used for the simulated die away curve that best-matches a given measured die-away curve from DAN are inferred to be representative of the actual composition and geometry at the measurement location [12].

As with previous analyses of DAN-active data [6], we have used the average Gusev Crater regolith composition measured by the Alpha Particle X-Ray Spectrometer (APXS) on Mars Exploration Rovers (MER) [13] as our background composition. The regolith density for these simulations is constant at 1.8 g/cm^3. Density is calculated from the standard regolith density over the first 1900 m of the MSL traverse [7].

The parameters we explore are from the results published in [10]. The five parameters and their corresponding ranges of values are:

- Average WEH within a single homogenous regolith (1.85 – 2.88 wt.%)
- Average AEC within a single homogenous regolith (0.7 – 1.7 wt.%)
- Average WEH in the top layer of the regolith in a two-layer model (0.80 – 2.02 wt.%)
- Average WEH in the bottom layer of the regolith in a two-layer model (1.8 – 3. 7 wt.%)

- The depth to the second layer (0 – 40 cm)

Using the library of Geant4 simulated die-away curves we will use the statistical methods from [12] to determine the best fit, and compare the results to those found in [10]. In addition to reproducing simulation results from [10] with Geant4, we will use benchmark code written in MCNPX to compare the fit results.

Preliminary Results: We are in the process of writing Geant4 code that mimics the MCNPX simulations published in [10]. The Geant4 package is now accessible on The University of Tennessee's Advanced Computing Facility (ACF). We will present the progress of building the library of die-away curves simulated using Geant4. Once complete, the Geant4 simulations can be used to analyze any DAN active measurement.

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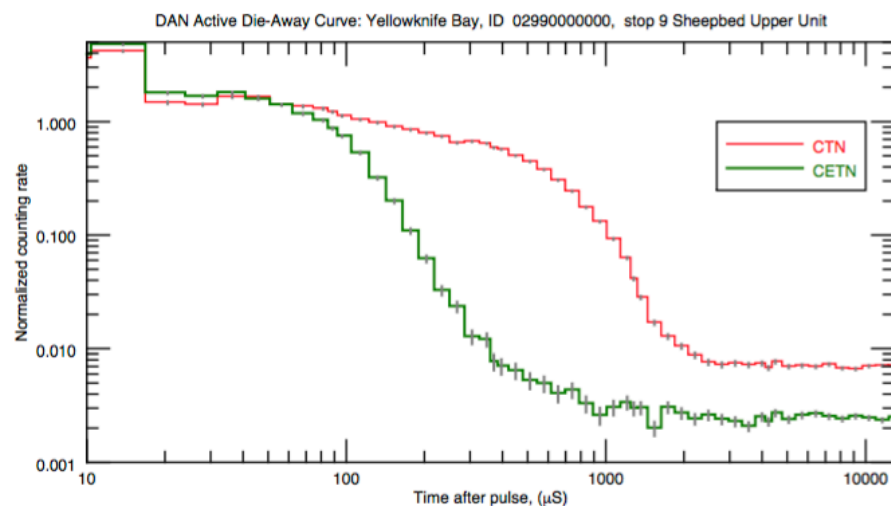

Figure 1: *DAN-active measurement taken directly from the PDS. This single die-away curve is from Upper Sheepbed Unit in Yellowknife Bay, stop 9.*