Content of Hydrogen at testing spots of the Gale crater: the first data from DAN onboard the Curiosity Mars Rover.

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Introduction: The name of the DAN [1] instrument comes from the abbreviation of the name of the physical process of *dynamic albedo of neutrons*, which takes place when neutrons are produced by the *Pulsing Neutron Generator* (PNG) that has an initial energy of 14 MeV that is released (leaked) from a tested substance with a time delay as large as several milliseconds. This leakage is the diffusion process, when neutrons make a large number of collisions with nuclei of the atoms of the substance encountered. This diffusion of neutrons results in a moderation of the neutron's energy, since particles lose a fraction of energy in each collision. When a substance contains atoms of hydrogen, neutrons lose about half of their energy at each collision with them. In this case moderation becomes more efficient, and a large fraction of neutrons leak after having been completely thermalized. Moreover, the die-away emission is much longer for thermal neutrons, because such particles with thermal velocity need more time for diffusion than fast or epithermal neutrons.

Figure 1. Two blocks of the DAN instrument: the DAN PNG block *(top)* for pulsing neutron generation and DAN DE block (*bottom*) for obtaining measurements of the die-away time profiles of thermal and epithermal neutrons.

Method of investigation: The method of nuclear remote sensing is used by the DAN instrument onboard the *Curiosity* Rover for studying the distribution of hydrogen with a linear resolution of about 3 meters along the traverse and within a shallow subsurface down to ~1 meter. These linear scales correspond to the free path of the initial 14 MeV neutrons down to subsurface and the diffusion length of leaking particles back to the surface. Therefore, the distribution of hydrogen over the measurement area is physically averaged over these scales. This averaging is the main difference of the DAN investigation in comparison with measurements of hydrogen within a small tested sample of a regolith by such instrument as SAM [2]. One would predict the essential difference between the data for hydrogen from DAN and SAM or other analytic instrument, which actually represents the expected distinction between the average content of hydrogen inside several cubic tons of regolith in the subsurface and the sample of several grams taken from some point on the surface.

The second peculiarity of the DAN method is the necessity of the model dependent deconvolution of measured die-away time profiles of albedo epithermal and thermal neutrons into the in-depth distribution of hydrogen in the testing spot below the Rover (see [1] for details). As the first step, the content of the soil-constituting elements is assumed to be the same over the all testing spots, and measured variations of albedo neutrons are thought to be associated with the changes of water content in the testing spots. It is quite correct for the main elements, which all have the similar effects on the neutrons diffusion. It is not the case for elements with large cross-section for thermal neutron absorption, such as Cl and Fe. However, below we consider the variation of absorbing elements, as the secondary effect for neutron die-away flux variations in comparison with the primary effect due to variations of the hydrogen.

The method of neutron data deconvolution is based on the direct comparison between the measured die-away time profiles of the epithermal and thermal neutrons in the testing spot with the corresponding time profiles predicted by the numerical simulations of the process of dynamic albedo of neutrons for the model of the soil with the particular composition (see [1] for details). For the preliminary analysis of DAN data, we used the standard composition of the soil (see [3]).

Testing the homogeneous models of the soil composition: The simplest model of regolith was one with the same content of hydrogen over each individual tested spot, both in length and in depth (*homogeneous model*). It has only one fitting parameter ζ, the *Water Equivalent Hydrogen* (WEH) measured in wt% of water in the soil. The model was compared with observational data at different spots of the Rover along the first ~500 meters of moving over the Gale. To make this comparison, two Quick Look parameters QL2 and QL4 were used, which are based on the experimental data.

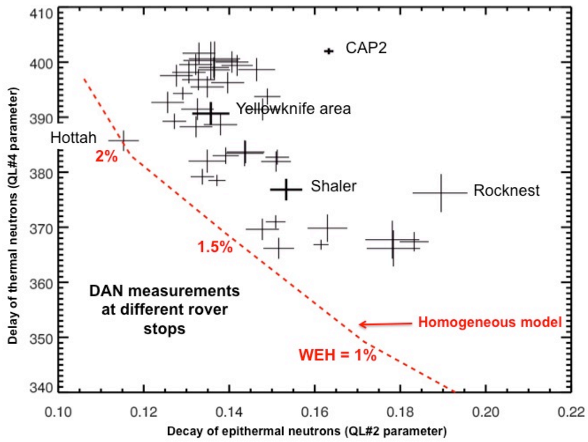

Figure 2. Measurements of QL2 and QL4 for all stops of the Rover along the first ~500 meters of the traverse. The *red* curve corresponds to the prediction of the homogeneous model of hydrogen distribution.

The parameter QL2 is the ratio of fluence of epithermal neutrons measured in the interval [132-300 μs] and [45-300 μs], it characterizes the slope of the decay of epithermal neutrons after pulses. The parameter QL4 is the average time of leakage of thermal neutrons, as measured in microseconds within the time interval [50-1000 μs] after pulses. Neither parameter depends on pulsing intensity or on the efficiency of sensors, so they are thought to be the best observational signatures for hydrogen content in the subsurface. Figure 2 presents the values of QL2 and QL4 for all spots in comparison with the prediction of the homogeneous model. It is evident that data for only one measurement in the spot of *Hottah* agrees with this model: the WEH corresponds to ~2 wt% at this stop. The data for all other measurements are many *sigmas* from the red curve: these data do not support the homogeneous model.

Testing the 2-layer model of the soil composition: The *2-layer model* is the next after the homogeneous model level of complexity: it corresponds to 2 layers with different contents of hydrogen. There are three free parameters of this model: WEH ξ_{up} in the top layer, thickness h of the top layer and WEH ξ_{down} in the bottom layer below the top one. Estimated values for content of hydrogen are obtained in the layered subsurface in each particular tested spot with active DAN measurements. The content of hydrogen in the top layer was found to be practically the same at stops, the value of ξ_{up} was about 1.0 – 1.5 % WEH (Figure 3).

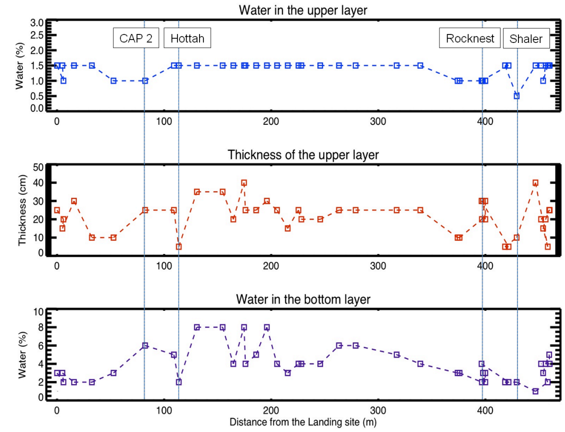

Figure 3. The best fitting values for parameters of 2-layer model for all stops of the Rover for the first ~500 meters of the traverse: the content of water ξ_{up} in wt% WEH (*top*), depth h in cm (*middle*) and the content of water ξ_{down} in wt% (*bottom)* are shown. Parameters for the particular spots are shown by the vertical lines.

The other two parameters of 2-layer model were found to vary from one testing spot to another, the best fitting values of these parameters are shown in Figure 3. For the distance interval of [0 – 100 m] and for the interval of [220 – 500 m] the bottom layer is found to have hydrogen with a variable content 2 – 6 wt% WEH at the depth of about 10 – 30 cm. For the distance interval of [100 – 220] hydrogen content is more variable with limits of 4 – 8 wt% WEH, the depth is also somewhat larger, 20 – 40 cm.

Conclusions: The first data analysis of DAN investigations show that content of hydrogen is different at different testing spots. The data is consistent with the simple 2-layer model with "dry" layer on the top of the "wet" one, and spot-to-spot variations are mainly associated with the depth/hydrogen of the bottom layer. In some spots the estimated content of water in the subsurface is as large as 8 wt% WEH. Further analysis will include joint analysis of active and passive data and orbital measurements [4]. Also, content of soil in the testing spots [5] and the morphological variations along the traverse [6] will be taken into account.

References: [1] Mitrofanov I.G. *et al.* (2012), *Space Sci. Rev*., 170, 559-582. [2] Grotzinger J. *et al.* (2012), *Space Sci. Rev*., 170, 5-56. [3] "The Martian Surface. Composition, Mineralogy and Physical Properties", ed. by J. Bell (2008), Cambridge Univ. Press. [4] Litvak M. *et al*., LPSC 2013. [5] Hardgrove C. *et al*., LPSC 2013. [6] Kuzmin R.O. *et al.*, LPSC 2013.