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PHYSICS

Studying of Water Consent in Mars' Gale Crater: The First Results of the DAN Experiment on the NASA Curiosity Rover[1]

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Mars's Gale Crater is located near the equator and is 155 km in diameter. The crater is estimated to be 3.5–3.8 billion years old. It originates from a large asteroid strike in the Noachian period. The crater's floor is 2–4 km below its surroundings. According to the current view (see [1]), early in Mars evolution the crater contained a lake with numerous rivers flowing in During the lake's lifetime, sedimentary deposits accumulated on the crater's floor in a layered structure reflecting the ongoing changes in the ancient Martian climate. After the whole-planet dehydrated, the bottom of the dried-up lake eroded. As a result, distinctly deposited layers are exposed in different regions, which were formed under different climate conditions.

The primary scientific objective of the NASA Curiosity rover is to find out whether the early Mars environment was favorable for the origin and sustenance of primitive life forms. The answer to this question may be obtained from the Martian soil samples analyses by the instruments onboard the rover [2]. As the origin and sustenance of terrestrial life are generally accepted to be directly related to water, "follow the water" became the unofficial motto of the NASA Mars Exploration Program. Accounting for this, the Curiosity Rover's scientific payload includes DAN, the Dynamic Albedo of Neutrons experiment, a Russian instrument for active-pulsing neutron probing of the near-surface soil [3, 4].

The method is based on the significant dependence of the surface-reflected neutron flux spectrum and time profile (*neutron albedo*) on the content of hydrogen nuclei in the soil. Neutrons lose energy by colliding with atomic nuclei in the soil during diffusion, with the energy loss proportional to the neutron-to-nucleus mass ratio. Consequently, collisions with the soil-constituting elements (O, Si, Al, Mg, Ca, Na, S, P, Ti) lead to minor energy losses, while for collisions with hydrogen nuclei, which are just protons, neutrons lose a significant part of their energy. As the hydrogen percentage in the soil increases, the relative fraction of these moderated neutrons also increases, with a significant part of the neutrons leaking out from the subsurface at thermal energy The thermal neutron flow, as detected by the instrument electronics, peaks at 200–300 microseconds after the neutron pulse (Fig. 1). As water is believed to be the main chemical substance containing hydrogen in the Martian soil, the active neutron probing provides a means of measuring water content along the traverse of the rover. The leaking neutron flux also changes with variations in the abundance of elements with high capture cross-sections. The main neutron absorbers in the Martian soil are chlorine and iron (see [5]). As chlorine is known [6] to have larger spatial variations than iron on the surface of Mars, the interpretation of active neutron data should primarily take into account chlorine variations.

The DAN instrument consists of a pulse neutron generator and a detector electronics module for thermal and epithermal neutrons [4]. The generator produces pulses of 14.1 MeV neutrons with a duration of

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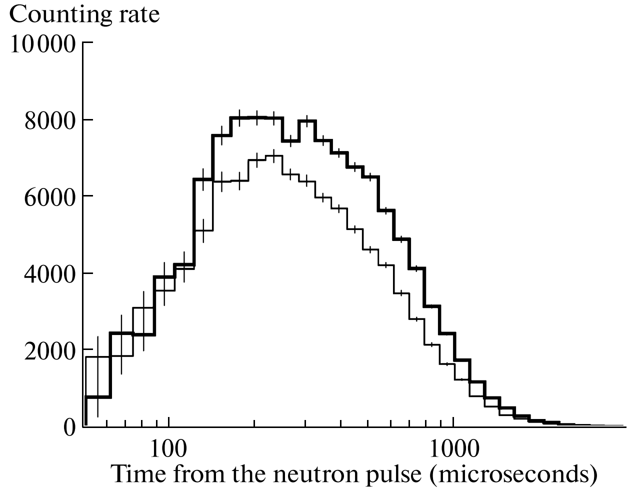

Fig. 1. Examples of DAN measurements for time profiles of thermal neutrons (energies <0.4 eV) along the time scale with zero moment corresponding to the initial pulse of 14.1 MeV neutrons from the PNG. The numerical simulations shows that two measured time profiles shown by bold and thin lines correspond to maximal 3% and minimal 1% estimations of water content, respectively.

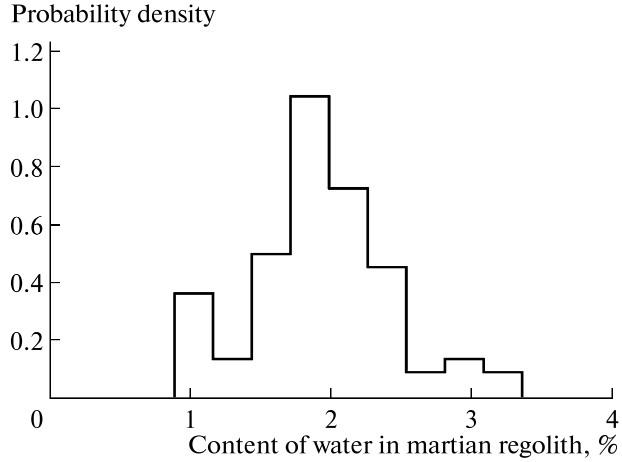

Fig. 2. Distribution of the average content of water in the upper most layer of 60 cm along the rover traverse for the 1st year of DAN operations.

about 2 microseconds. For the detector module, two identical proportional counters are used, filled with 3He gas pressurized up to 3 atm. The epithermal neutron counter (CETN) is wrapped in a 1 mm thick cadmium enclosure. As cadmium has a high cross-section for capture of neutrons with energies below 0.4 eV, the CETN detects only epithermal neutrons with energy above this threshold. The second detector, CTN, has no cadmium shielding and detects both thermal and epithermal neutrons. The difference in count rates between CTN and CETN (the so-called *cadmium difference*) corresponds to the reflected flux of thermal neutrons. The data analysis for thermal and epithermal neutrons makes it possible to determine the distribution of chlorine and water down to 60 cm from the surface within a 3-meter spot under the rover. Experimental data processing is based on comparing the DAN measured time profiles of post-pulse neutron emission with numerical simulations for different soil models (see [4]). These models assume a fixed, homogeneous percentage of soil-constituting elements, while the water content, the chlorine content and soil density may vary. The second group of models consists of two distinct surface layers, where the water content is assumed to be different between the variable-depth top layer and the bottom layer.

The DAN instrument has performed more than 120 active measurements of 5 to 15 minutes duration each over the first year on the surface of Mars, since August 9, 2012. More than 10^{13} neutrons have been produced by the generator and about 5×10^6 surface-reflected neutrons have been detected. Best-fit parameter estimates have been obtained from the soil models for 98% of the measurements.

Figure 2 shows the distribution of average water content within the top 60 cm of the subsurface. The mass content is in the range of 1 to 3% with an average of 1.9%. The soil density varies slightly in the range of 1.5–2.2 g/cm^3 with an average value of 1.85 g/cm^3, while the chlorine content varies from 0.75 to 1.75% with an average value of 1.1%.

This estimate of water content in Gale Crater comes close to the percentage of water in the surface soil of the driest Earth deserts (e.g. see [7]). However, this does not contradict the hypothesis that the rover is standing now on the bed of an ancient water body—as the Atacama Desert, which is the driest desert on the Earth, is also known to be an ancient seabed. After the lake in the Gale Crater had dried out, both free and adsorbed water in the soil evaporated into the Martian atmosphere. The low water content observed today might indicate the presence of some fraction of hydrated minerals in the near-surface layered deposits, which are known to not lose water by natural evaporation, preserving it in a chemically bound state. Taking the percentage of water in the hydrated minerals to be up to 10–15%, the estimates obtained above are consistent with a hydrated mineral content of 7–30%.

On the other side it is important to mention that the water and chlorine content estimates based on DAN data differ significantly from the estimates based on the orbital neutron and gamma-ray measurements on board the NASA Mars Odyssey orbiter. The latter suggest an average water and chlorine mass content around the Gale Crater to be 4–5 and 0.6–0.7%, respectively [6, 8]. Two possible explanations can be suggested for this discrepancy. Firstly, the orbital measurements have a spatial resolution of about 600 km on the surface, while the DAN data have been obtained from a ~1 km long traverse. The rover may turn out to be positioned in the driest part of Gale Crater. Secondly, the orbital experiments measure the nuclear radiation of the surface induced by galactic cosmic rays within the upper most 1-meter layer, while the neutron generator probes to a depth of only 60 cm. Soil with a high water content of water of >5% may lie under the 60 cm of relatively dry layer.

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