3-D IMAGING OF SUBSURFACE IN PLANETARY MISSIONS BY ACTIVE GAMMA-RAY SPECTROSCOPY. M. L. Litvak[1], Y.N. Barmakov[2], S.G. Belichenko[2], E.P. Bogolubov[2], A.S. Kozyrev[1], I.G. Mitrofanov[1], A.V. Nosov[1], A.S. Perkhov[1], A.V. Samoshin[2], A.B. Sanin[1], S.E. Sholeninov[2], V.N. Shvetsov[3], D.I. Yurkov[2], A. O. Zontikov[3], V.I. Zverev[2], [1]Space Research Institute, Moscow, Russia, 117997, litvak@mx.iki.rssi.ru, [2]Federal State Unitary Enterprise «All-Russia Research Institute of Automatics» (VNIIA), Moscow, Russia, [3]Joint Institute for Nuclear Research, Dubna, Russia.

Introduction: Gamma-ray spectrometers (GRS) were developed for many space missions to derive the subsurface bulk elemental composition in orbital or surface observations. It is expected that such studies will be frequently carried out in the near future on Mars and Moon surfaces. The gamma-ray and neutron spectroscopy instrumentation usually detect such elements as O, C, Na, Mg, Al, Si, Ca, K, Fe and some others, see for example [1]. The Galactic Cosmic Ray (GCR) charged particles produce secondary neutron emission via spallation reactions with soil nuclei. The neutrons in their turn interact with soil nuclei, excite them and lead to the characteristic gamma emission during nucleus deexcitation to the ground state. The same result could also be achieved by artificial radiation sources like neutron generators (NG). NG can irradiate subsurface under the landing platform with intense flux of fast neutrons. Such approach is informally called as an active gamma-ray experiment [2,3]. It significantly enhances measurement capabilities due to much higher counting statistic (leads to higher accuracy) and separation between different gamma emission processes. This technique is being used in various Earth applications including geology, security, medicine and etc. [4,5]. It has also been proposed for space experiments and is actively considered for the future planetary missions [3,6]. In space until now it was implemented only for neutron spectroscopy measurements [2,7]. A gamma-ray spectroscopy allows to remotely measure the bulk elemental composition of planetary soil down to 1 m depth. It is significant advantage in comparison with many other techniques aiming to the measurement of soil composition. However, unfortunately, with this method, it is very difficult to distinguish between the signal from the subsurface being investigated and the background signal originated from the body of lander or rover module. It could be resolved in active observations where gamma-rays are selected by solid angle and by time of flight technique. This technique is known as the associated particle imaging (API, and it is also called tagged neutrons method (TNM)). It is already used in industry applications, especially in search for explosive materials. The main purpose of the measurements is to collect gammas produced in the object under study and reject gamma detections from the surroundings [8].

In this study we report the results from ground tests with the TNM/API instrumentation. We have shown that these methods can provide true identification of the bulk subsurface elemental composition (major rock forming elements) together with the robust elimination of the parasite spacecraft background as well demonstrate capability to perform 3-D analysis of the subsurface layering structure.

Instrumentation: It consists of a gamma-ray spectrometer ($LaBr_3(Ce)$) and a neutron generator with a position-sensitive alpha particle detector (ING-27, developed by the Dukhov Research Institute of Automatics). The neutron generator emits continuous flux of fast neutrons (14 MeV) using nuclear fusion reaction $T(d,n)^4He$. The reaction products, neutron and alpha particle, are emitted in opposite directions, so the detection of alpha particle with the position sensitive detector determines the emission time and the direction of the fast neutron. The detections in the pixelated alpha particle detector can restrict the specific solid angle and select only those neutrons which escape in the definite direction. In our experiment it was the subsurface of soil simulant (imitates average martian soil composition) right under GRS. Fast neutrons travel with a constant velocity of about 5 cm/ns and hit the soil simulant and produce characteristic gammas via inelastic reaction with soil simulant nuclei. Some of these photons are detected by GRS.

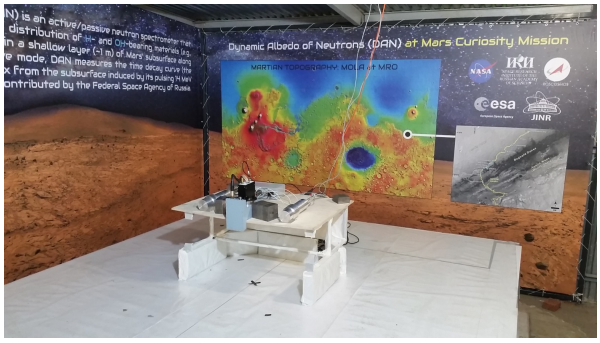

Figure 1. Photo of the experimental setup: GRS and NG above soil simulant.

The measurement of time interval between detections of the alpha particle and the gamma photon with nanosecond accuracy defines a location where the

interaction between the neutron and the target's nucleus occurred. This technique reduces the background counting rate from the surrounding material by orders of magnitude. Time of flight or time coincident technique marks the neutrons interacted with soil nuclei in the particular part of soil simulant. For example, one may select time window with only neutrons arriving from the top of the soil simulant or from the definite depth. The time resolution of GRS is limited with 1±0.5 ns uncertainty. Taking into account that the velocity of neutron is about 5 cm/ns one may speculate that this observational method can select photons produced in the subsurface layer with a thickness around 5 cm. Thus, one may try to detect subsurface layer with unique elemental composition.

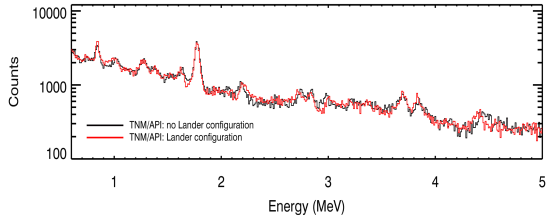

Figure 2. Integrated gamma spectra measured by the TNM/API methods for the "lander" (red color) and the "no lander" (black color) configurations.

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