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# Associated-particle imaging technique application for study of planetary subsurface soil elemental composition

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Nuclear instrumentation based on neutron and gamma-ray spectroscopy are often used in planetary missions to derive the bulk elemental abundances of the subsurface. Some of them are specially designed for the landing missions and combine gamma ray spectrometers and pulse neutron generators. We present the results of ground tests aimed to study applicability of "associated-particle" imaging technique for the subsurface elemental analysis onboard future landers and rovers. This method has been developed for various geology and security (for example to detect explosive materials) applications. The "associated-particle" imaging technique uses t(D,n)4He nuclear reaction for producing the fast neutrons with energy of 14.1 MeV. The neutron and a-particle (with energy 3.5 MeV) produced in this reaction coming out in the opposite directions . Thus, the measurements of the a-particle trajectory could determine the neutron's direction. Neutrons interact with the planetary soil and produce the gamma-rays in inelastic reactions with soil nuclei. The knowledge about neutron's direction and using time of flight technique helps to select only gamma-rays which were produced within definite solid angle. It could be used to substantially increase signal-to-background ratio by selecting gamma rays from the subsurface and rejecting detection of gamma ray background from the spacecraft body.

We assembled a simulant of planetary subsurface and conducted series of ground tests with measurements of gamma-rays produced in the planetary material using "associated-particle" imaging technique. All measurements have been performed at the Joint Institute for Nuclear Research (JINR) in Dubna, Russia, in a facility designed for ground testing with space instrumentation such as active neutron and gamma-ray spectrometers. We have used a large bed of planetary material simulant with a surface area of 3.21 m$\times$3.83 m and a depth >60 cm. The planetary material simulant presents a multilayered structure where layers of silicon rich glass (thick ness of one layer is 10 mm) alternate with thin (0.7–1 mm thickness) layers of steel (Fe rich material), aluminum alloy (Al rich material), and polyvinylchloride (Cl rich material) to achieve average planetary elemental compositions applicable for Mars, Moon, Mercury, and Venus (major elements Si, O, Al, Mg, Fe, K, Na etc).

We have demonstrated that "associated-particle" imaging technique provides following measurements advantages which make this approach perspective for the planetary mission applications:

1) High signal-to-background ratio for gamma-ray lines with respect to the standard gamma-ray spectroscopy methods;

2) The detection of subsurface structure with identification of layers with 10 cm depth resolution.