NUCLEAR INSTRUMENTS AND METHODS FOR SPACE PLANETOLOGY: RECENT RESULTS AND NEW DEVELOPMENTS.

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Introduction: Nuclear physics is shown to provide the unique opportunities to study from interplanetary spacecraft planets and small bodies of solar system, which are not possible for any other methods of investigation. The following tasks are identified for space experiments with nuclear instruments onboard orbiters and landers:

(1) To determine the content of natural radioisotopes *K, Th* and *U* in the material of different planets and celestial bodies of the solar system for understanding the processes of their origin and evolution.

(2) To study composition of subsurface material at different regions of planets for modeling processes of their formation and for explanation of their diversity.

(3) To investigate distribution of water in the shallow subsurface of Mars, Moon and Mercury, to test the presence of deposits of pure water ice, as the soil constituting substance, at some particular regions on their surfaces.

(4) To characterize radiation conditions in the interplanetary space and on the surface of planets, to determine potential radiation hazards during long-duration space flight and long-duration stay on Moon and Mars.

Recent results and directions of further investigations: Moon and Mars are only two celestial bodies, which natural nuclear emission has been measured by the method of remote sensing from the orbit. Historically, Soviet Lunas and American Appollos have pioneered these investigations of the Moon in 60-th years of the last century (e.g. see [1, 2]). In 90-th, the US Lunar Prospector mission has performed global orbital imaging of lunar natural emission of gamma-rays and neutrons, which provided the first maps of distribution of radioisotopes and soil constituting elements over the entire lunar surface [3]. The most intriguing finding of this mission were extended polar depressions of flux of epithermal neutrons, which were interpreted, as the possible evidence for water ice deposits at polar cold traps on the Moon [4]. However, that nuclear instrumentation did not provide high enough spectral resolution of gamma-ray nuclear lines and accurate enough spatial resolution both at gamma-rays and neutrons for analysis the diversity of regolith composition at the length scale of tens of kilometers and also for conclusive testing of water ice deposits at lunar poles.

The next step in the orbital nuclear remote sensing was made by NASA's Mars Odyssey mission, which is still successfully operating on the Martian orbit since 2001 with gamma-ray spectrometer GRS and two neutron spectrometers HEND and NS [5]. One of the most important findings of this mission was discovery of water ice with very high content in the shallow subsurface of Mars practically everywhere above the latitude of 60° both at north and at south [6 – 8]. The data from Odyssey gamma-spectrometer with high purity *Ge* has demonstrated the necessity of high spectral resolution for reliable mapping of key elements over the surface, but spatial accuracy of these maps has still been limited by very poor linear resolution with the scale of an orbital altitude. Presently, two more gamma-ray spectrometers with high purity *Ge* are operating in space: one is measuring lunar gamma-ray emission from the board of Japanese Kaguya spacecraft; another is flying to Mercury onboard NASA's Messenger.

The main direction of further development of the method of nuclear remote sensing is thought to be increasing of linear resolution of measurements from the orbit, which shall allow to identify features at images of nuclear emission with particular landscape objects on the surface. The spatial resolution is necessary for these measurements with a scale about 10 – 30 kilometers.

The only surface landers with nuclear instrumentation onboard were Soviet Venera and Vega missions, which provided the first experimental estimations of content of *K*, *U* and *Th* in the Venus soil. However, accuracy of these values was quite poor and did not allow to make the accurate comparison of *Th/K* ratio of Venus with similar parameters for Earth, Mars and Moon. Also, the thick atmosphere of Venus protects the surface from galactic cosmic rays, and therefore there is no secondary nuclear emission of subsurface, which one may measure to determine the soil composition.

Future nuclear instruments for measurements on the surface of Moon, Mars and Venus are thought to apply neutron activation method for studying subsurface composition, which provides the most accurate evaluation of contents of individual elements and also may allow to resolve a layering structure of subsurface.

Instruments under development for nuclear remote sensing: The first neutron telescope with fine spatial resolution is LEND (Lunar Exploration Neutron Detector) for NASA's Lunar Reconnaissance Orbiter [9]. The main goals of LEND investigation are related with the particular capability of this instrument to image neutron emission of the Moon with a spatial resolution of 10 km. These goals are – testing of water ice at bottoms of permanently shadowed polar craters and mapping the hydrogen distribution on the Moon surface with statistically-driven spatial resolution from 10 to 30 km. The LRO mission is scheduled for launch in the April 2009, and the first LEND data for neutron emission from the polar craters shall be available within 2-3 months after the launch.

Russian neutron telescope LEND is considered as a prototype for several future nuclear instruments, which concepts will be presented in this talk. Their goals are detailed global mapping of neutron and gamma-ray emission from Moon and Mars with fine spatial resolution. One of them could be exact copy of LEND, but for orbiter around Mars. With orbital altitude of 200 km, this neutron telescope shall image the neutron emission of the Martian surface with resolution of about 40 km – this linear resolution is about 10 times higher than current resolution of neutron maps from Mars Odyssey. One may use the imaging data for landing site selection of future landers on Mars, provided high content of water would become one of selection criteria for this site.

Next step of development of instrumentation for nuclear remote sensing shall be orbital collimated gamma-ray telescope, which imaging capability may correspond to a linear scale of 10 – 30 km. The concept of this instrument will be presented in this talk, as based on the integrity of fine spatial resolution for surface mapping of gamma-ray emission with high spectral resolution and high detection sensitivity for nuclear lines. Scintillation detectors with $LaBr_3$ crystals will be used as detectors for this telescope, because they have spectral resolution as high as 3% for gamma-rays at 662 keV. The first orbital instrument with such innovative detector is Mercury Gamma and Neutron Spectrometer (MGNS) for ESA's mission BepiColombo to Mercury [10].

We believe that one could not be able to design the program of utilization of lunar resources without accomplishment of orbital reconnaissance mission for mapping the composition of lunar regolith with a linear resolution about 10 – 30 km. Such gamma-ray telescope for future Lunar Orbiter is now under development in the Russian Space Agency.

Instruments under development for landing missions: Future NASA's rover Mars Science Laboratory has Russian instrument DAN onboard [11]. Instrument DAN (Dynamic Albedo of neutrons) implements the method of neutron activation to measure the content of hydrogen in the soil along the trace of the rover within a scale of 1 meter. Pulsing neutron generator of DAN produces pulses of 14 MeV neutrons with a number of about 10^7 particles per pulse, and sensors of DAN measure die-away curves of emission of moderated neutrons after each pulse. Intensity and time profile of the dynamic albedo of neutrons provide the opportunity for accurate estimation of content of hydrogen in the soil and also for testing the layering structure of hydrogen content within a depth of about 1 meter. DAN shall operate continuously during the MSL surface operations, and data from this instrument may allow to select the most interesting water-rich spots for their detailed investigation by all other instruments onboard MSL.

In future, design of DAN shall be used for development of instruments for future landing missions. The concept of neutron and gamma-ray spectrometer with neutron activation will be presented in this talk. In addition to neutron generator and neutron detectors, this future instrument will also include gamma-ray spectrometer with fast counts processing for measurements of die-away emission of activated nuclear lines from a soil. One of future mission with such instrument with neutron activation capability will be Russian Lunokhod (Moon rover), which will use this technique for studying soil composition along a trace and for selection the most interesting samples of lunar regolith for sample return mission. Another instrument with neutron activation capability may be developed for future landing mission on the Venus – neutron activation technique is the only possible method for measuring the bulk composition of Venus soil within a volume of about 1 meter around the lander.

Conclusions: Presently, nuclear instruments have become well-developed part of the scientific arsenal for exploration of Moon, Mars and another bodies of the solar system. Even more progress in the development of this instrumentation could be expected in future. Designers of new interplanetary missions will take into account the unique capabilities of these instruments. As well, nuclear physicists shall design new space instruments, which will be capable to count nuclei of particular elements in the extraterrestrial soils both remotely and on the surface. Integrity of these two efforts promises intriguing progress of solving of Tasks (1) – (4) of "nuclear planetology" in the future.

References: [1] Vinogradov A. et al. (1966) *Cosmic Research 4*, 751. [2] Metzger A. et al. (1973) *Science 179*, 800. [3] Feldman W. et al. (1998) *Science 281*, 1496. [4] Feldman W. et al. (2001) *JGR 106*, 23231. [5] Boynton W. (TBD) *Space Science Rev. 10, issue 1*, 37. [6] Boynton W. et al. (2002) *Science 297*, 81. [7] Feldman W. et al. (2002) *Science 297*, 75. [8] Mitrofanov I.G. et al. (2002) *Science 297*, 78. [9] Sanin A. et al. (2009), this conference. [10] Kozyrev A. et al., (2009), this conference. [11] Litvak M. (2009), this conference.