FINE RESOLUTION EPITHERMAL NEUTRON DETECTOR (FREND) FOR MAPPING MARTIAN WATER FROM THE ESA'S TGO. I. G. Mitrofanov[1], A. B. Sanin[1], A. V. Malakhov[1] , Yu. I. Bobrovnitsky[2], T. M. Tomilina[2] and F. V. Fedosov[1], [1]Institute for Space Research, Profsojuznaja 84/32, 117997 Moscow, Russia (imitrofa@space.ru), [2]A. A. Blagonravov Institute of Mechanical Engineering, Malyi Khariton'evskij 4, 101990, Moscow, Russia.

Introduction: At the first stage of the ExoMars program in 2016 – 2017 ESA plans to study the martian atmosphere and the surface from the Trace Gas Orbiter (*TGO*) and to perform the testing landing of the Entry, Descent and Landing Demonstrator Module (*EDM*). Currently the ExoMars program is agreed, as the joint effort of ESA with the Federal Space Agency of Russia (Roscosmos). The Fine Resolution Epithermal Neutron Detector (*FREND*) is described below, as the Russian contributed instrument for ESA's *TGO*.

The heritage of *FREND* investigation: The Figure 1 presents the map of the epithermal neutron emission of the martian surface made by the High Energy Neutron Detector (*HEND*) onboard NASA's *Mars Odyssey* [1]. HEND is the part of Gamma-Ray Spectrometer suite onboard this spacecraft [2]. Using the data from this suite, it has been unexpectibly found that emission of epithermal neutrons is highly variable over the Martian surface. The total dynamic scale of variations corresponds to a factor of ~ 6, while variations at the equatorial belt within ± 30°of latitude corerspond to a factor of ~ 2 (see Figure 1).

HEND is the instrument with omni-directional sensors of neutrons, and the spatial resolution of measured maps is ~ 600 km, which is resulted from the the orbit altitude of 400 km. Such large variations of neutron flux ~ 6 times at the large distance scale about 600 km allow to suspect that much larger variations might take place at smaller scales. The most interesting scale of neutron variations corresponds to several tens of km, which is about the size of distinct landforms on the surface. To study such variations, one needs much better spatial resolution than HEND has.

Such instrument was proposed in 2005 - 2007 for neutron mapping of Moon and Mars [3, 4]. Its major difference from the *HEND* is the neutron collimation modile. When the collimated instrument is pointed to nadir from the orbit, the large fraction of detetcted neutrons is coming inside the "open" hole, which produces the instrument Field of View (*FOV*). Such innovative technique has been initially implimented for the Lunar Exploration Neutron Detector (*LEND*) onboard the NASA's Lunar Reconnassance orbiter (*LRO*) for testing polar deposits of water on the Moon [5]. Obtained results has successfully proved the method of neutron collimation, as the searching tool for the water-rich local spots on the surface of an atmosphereless planetary body (e.g. see [6, 7]).

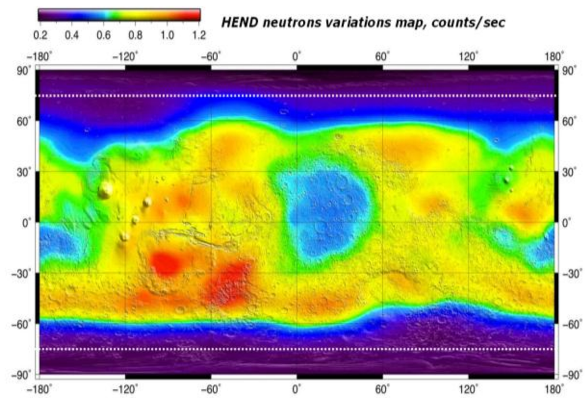

Figure 1: The *HEND* map of variations of epithermal neutrons emission on the Martian surface. Dotted lines correspond to highest north and south latitudes for mapping from the TGO orbit.

The *FREND* experiment concept is based on the heritage of *LEND* development [5]. There are three major differences of *FREND* in respect to *LEND*:

- *FREND* has no omnidirectional sensors for thermal and epithermal neutrons, which *LEND* has;
- *FREND* collimated sensors are shielded for neutrons produced by the spacecraft;
- *FREND* has additional block for dosimetry measurements.

The goals of *FREND* investigation: The *TGO* spacecraft will have the orbit with inclination of 74° and altitudes of 350 – 420 km. Such orbit allows to map the Martian surface from the equator upward to very high latitudes of 74° N and S (see Figure 1). The ***first goal*** of the *FREND* investigation is to map the emission of epithermal neutrons at the surface of such broad latitude belt with high spatial resolution about 40 km (Half Width Half Maximum, *HWHM*). The ***second goal*** of *FREND* is to measure the radiation dose at the *TGO* orbit from energetic particles of galactic cosmic rays and solar flares.

The concept of *FREND* design: The general view of *FREND* is presented in Figure 3. The central hole *1* of the neutron collimater create the Field of View (FOV) with the opening angle ~15° (HWHM) for high energy neutrons > 300 keV. Four holes *2* at corners of the collimater create the FOV with the opening angle of 5.6° (HWHM) for epithermal neutrons with energies >0.4 eV (see [5] for details). The box of electronics *3* includes also dosimeter for measuring the dose from charged particles at the energy range 0.1 - 80 MeV .

The science deck *4* is at the *-X* side of the nadir looking instrument, and its back side at *–Y* is shielded from neutrons of the spacecraft. The total mass of *FREND* is 36 kg, it is about 10 kg heaver than *LEND*. Additional mass is used for the back-side shielding.

Expected results: Under bombardment by galactic cosmic rays, Mars has about the same neutron emission as the Moon. According to the *LEND* data [6, 7], one may estimate the count rate of *FREND* collimated epithermal neutrons, as F_{FOV} = 1.5 cps (counts per sec).

FOV of collimated epithermal sensors corersponds to the linear spatial resolution about 80 km on the surface (FWHM) for the orbit with the altitude of 400 km. The nominal time of *TGO* mapping measurements T_{TGO} is about 1 Earth year. Using the 3σ criteria of confidence, one may estimate the low limit δ of the detectable relative variations of neutron emission at an elementary surface element about 80 x 80 km^2 at the equatorial latitudes, as the following:

$$\delta \sim 8\% \cdot (1.5\ \text{cps}/F_{FOV})^{1/2} \cdot (1 + k)^{1/2} \cdot (1\ \text{yr}/T_{TGO})^{1/2},$$

where k ~ 1 is the ratio between the count rate of the background and the count rate of collimated neutrons.

According to this expression, one should conclude that *FREND* would be capable to measure neutron variations >10% with the surface scale of 80 km. It is evident that such sensitivity is quite good for Mars. Indeed, one should take into account that variation of epithermal neutrons emission ~50% was measured by *HEND* with the resolution scale of ~600 km (see Figure 1). The ralative variations at much smaller scales of 80 km could be much larger, and *FREND* will be capable to measure them with rather high confidence.

The relative variarions of epithermal neutrons ~ 10% corersponds to variation of the water content in the soil about 0.1 wt% (e.g. see [6]). Such accuracy of water content mapping could be achieved by *FREND* for equatorial pixels with a size of 80 km. The accuracy will be even better for pixels at higher latitudes because time of exposure for them will be larger. The mapping of hydrogen/water on the Mars will be the ***first result*** of the *FREND* investigation.

The ***second result*** is the radiation dose characterization for the entire period of *TGO* operations: the rate of absorbed dose will be measured, as *Cy/hour*, with time resolution of 1 minute, and the spectra of ionisation losses will be measured with time resolution of 1 hour.

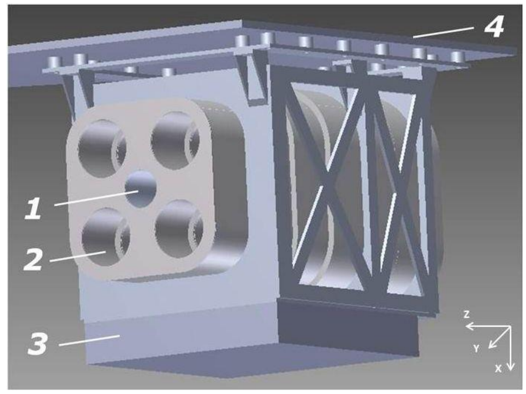

Figure 2. General view of *FREND* from the nadir direction.

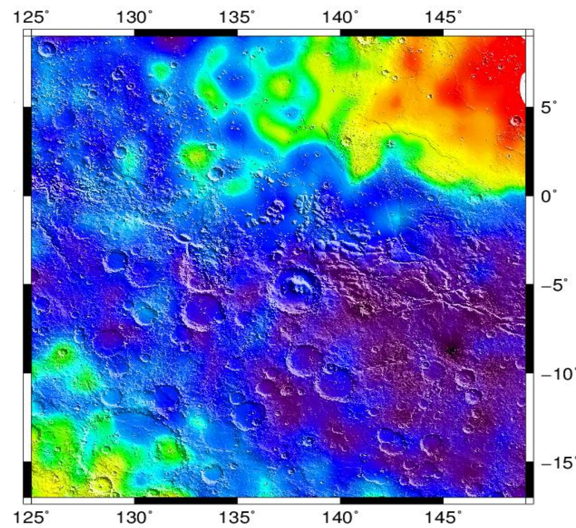

Figure 3: The *FREND* artificial map of epithermal neutrons emission at the vicinity of the crater Gale (spatial resolution is 40 km, *HWHM*).

Conclusions: At the current time the NASA's spacecraft *MSL* is heading to Mars for landing in the Gale crater. Figure 3 presents the artifical map of the Gale vicinity, as it could be measured by *FREND* with fine spatial resolution of 40 km This map shows, how the future maping from *FREND* would better correspond to the surface landforms with its ~ 10 times better resolution, than the map from the *HEND* (Figure 1)

References: [1] Mitrofanov I.G. et al. (2002) *Science* 297, 78. [2] Boynton W. V. et al. (2004) *Space Science Rev.* 110, 37. [3] Mitrofanov et al. (2005) LPSC XXXVI abstract #1879. [4] Mitrofanov I. G., Garvin J. B. and Sanin A. B. (2007) Seventh International Conference on Mars, abstract #3106. [5] Mitrofanov et al. (2010) *Space Science Rev*. 150, 183. [6] Mitrofanov et al. (2010) *Science* 330, 483. [7] Mitrofanov et al., (2011) *Science* 334, 1058.