THE MERCURY GAMMA-RAY AND NEUTRON SPECTROMETER (MGNS) FOR THE ESA BEPICOLOMBO MISSION

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Introduction: The Mercury Gamma-ray and Neutron Spectrometer (MGNS) has been proposed and selected for the payload of the ESA Mercury Planetary Orbiter of the BepiColombo mission, as the instrument for study of the elemental composition of the Mercury surface.

Mercury is the celestial body of the Solar system, after Mars and Moon, for which elementary composition of the shallow subsurface might be studied by observations of induced nuclear gamma-ray lines and neutron emission. Secondary gamma-rays and neutrons are produced by energetic galactic cosmic rays colliding with nuclei of regolith within a 1-2 meter layer of subsurface.

Nuclear gamma-ray lines from soil-forming elements are emitted either due to inelastic scattering of high energy neutrons or due to capture reactions of epithermal and thermal neutrons. Intensities of gamma-ray lines depend both on the elemental compositions of the subsurface and on the flux of neutrons. The knowledge of the spectral density of neutrons is the necessary condition for determination of the content of soil-forming elements using the data of gamma-ray spectroscopy. For that reason the nuclear experiment on BepiColombo includes both the gamma-ray spectrometer (GRS) segment for detection of gamma-ray lines and the neutron spectrometer (NS) segment for measurement of the neutron leakage spectral flux density.

There are three natural radioactive elements, K, Th and U, which contents in the celestial bodies soil characterize the physical condition of their formation in the protoplanetary cloud. The data from GRS segment will allow comparing Mercury with Earth, Moon and Mars.

Finally, mapping measurements of neutrons and 2.2 MeV line will allow us to study the content of hydrogen on the surface of Mercury. Neutron data are known to be very sensitive for detection of hydrogen within heavy soil-forming elements: the addition of as little as 100 ppm into a “standard” soil leads to decrease of flux of epithermal neutrons by about 5%. This decrease is resulted from efficient moderation of high energy neutrons by a soil with hydrogen nuclei [1-2]. The line at 2.2 MeV is emitted in the capture reaction $H + n \Rightarrow D$, when hydrogen capture thermal neutron and produce deuterium [3]. Therefore, both GRS and NS detectors of MGNS will allow us to test the enhancement of hydrogen (including that of water ice) in the permanently shadowed craters at poles of Mercury. These craters, as cold traps, are thought to accumulate hydrogen from solar wind during billion years of planetary evolution and/or water ice from impact with comets.

There are nine know models of the elementary composition of Mercury [4-7]. To test these models for particular regions of Mercury, MGNS will provide the data for the set of gamma-ray lines, which are necessary and sufficient to discriminate between the models. Also, known data for the composition of Mars [8] and Moon [9] will also be used as a testing model for MGNS performance.

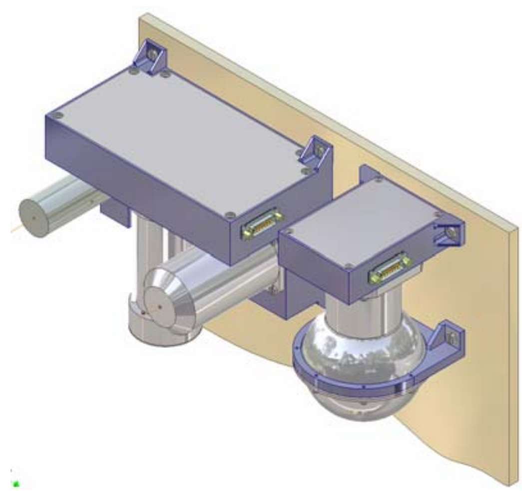

Figure 1. The main view of Mercury Neutron Spectrometer (NS) and Mercury Gamma-ray Spectrometer (GRS) accommodated on the science deck of the BepiColombo spacecraft.

Instrument description: The Concept design of GRS and NS segments are presented in Figure 1. Three sensors of NS for epithermal neutrons are made with similar ^{3}He proportional counters but have polyethylene enclosures with different thicknesses. The fourth sensor of NS for high energy neutrons 1-10 MeV contains an organic scintillator stilbene with high amount of hydrogen. Neutron detection by stilbene scintillator is based on reaction n + H ⇒ n' + p. The segment of GRS contains scintillation crystal $LaBr_3$ for detection of gamma-ray photons with excellent spectral resolution of 3 % at 662 keV.

The total mass of MGNS instrument is 5.2 kg; it consumes 4.0 W of power and provides 9.0 Mb of telemetry data per day.

Feasibility study: Comprehensive numerical simulation of gamma-ray and neutron emission of Mercury has shown that reliable statistics of photons will be accumulated for necessary gamma-ray lines provided the sensor is made of $LaBr_3$ crystal with efficiency corresponding to the volume of about 340 cm^3 (or linear size of about 7.5 cm). At the present time crystals of $LaBr_3$ of that size are not produced in the world leading research laboratories.

The MGNS team has conducted a study to prove technological feasibility of production of a $LaBr_3$ crystal of the size required on time for integration to the BepiColombo integration. It was shown, that the steady increase of high quality $LaBr_3$ crystals provides solid evidence for availability of a crystal of the necessary size of 340 cm^3 and necessary quality and volume in 2008-09. At present the researches have already produced the crystals of $LaCl_3$ of the necessary size, which are considered as a back-up option of the MGNS sensor. The $LaCl_3$ crystal has only slightly worse spectral resolution comparing to $LaBr_3$ (4% instead of 3% at 662 keV) with the same high efficiency.

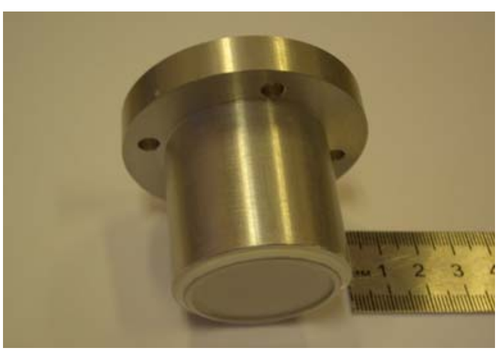

Figure 2. The scintillation crystal of $LaBr_3$ repackaged according to space qualification requirements.

As part of the feasibility study, tests of the $LaBr_3$ crystals were performed with beams of energetic particles in accelerator facilities. These tests have shown that crystals are very tolerant for high energy radiation and therefore they suite a long duration interplanetary mission into the inner Solar system perfectly.

Finally, re-packaging of a one inch $LaBr_3$ crystal has been done from the industrial container into the flight quality package (see Figure 2). This re-packaged sensor with the $LaBr_3$ crystal has been tested according to the BepiColombo environment requirements, including the thermal and mechanical load. After these tests the spectroscopic parameters were re-measured and found to be unchanged (see Figure 3).

Conclusion: At present, the nuclear instrument MGNS is under development for implementation on the MPO of BepiColombo mission, which will be able to provide observational data for mapping of soil composition of Mercury and testing possible hydrogen/water deposits at cold traps around the planetary poles.

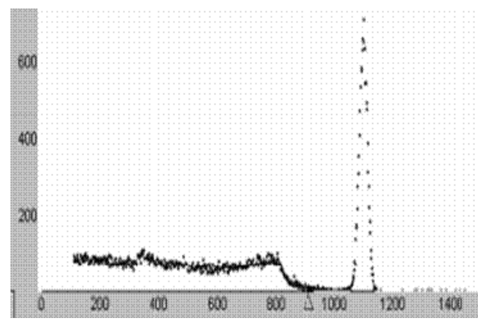

Figure 3. The energy spectrum of ^{137}Cs measured by the test sensor with $LaBr_3$ crystal after re-packaging. The spectral resolution at 662 keV corresponds to 3.0%.

References:

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