RADIATION ENVIRONMENT ON THE INTERNATIONAL SPACE STATION IN 2012 – SEPTEMBER 2013 ACCORDING DATA FROM LIULIN-5 EXPERIMENT

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***Key words**: space radiation, space radiation dosimetry, International Space Station*

***Abstract:** Since June 2007 the Liulin-5 dosemetric telescope has been observing the radiation characteristics in the spherical tissue-equivalent phantom of MATROSHKA-R project on the International Space Station (ISS). From 27 December 2011 to 8 September 2013 measurements were conducted in and outside the phantom located in the MIM1 module of ISS. In this paper attention is drawn to the obtained results for the radiation doses in and outside the phantom from galactic cosmic rays and trapped protons.*

РАДИАЦИОННАТА ОБСТАНОВКА В МЕЖДУНАРОДНАТА КОСМИЧЕСКА СТАНЦИЯ ПРЕЗ 2012Г-СЕПТЕМВРИ 2013Г СЪГЛАСНО ДАННИТЕ ОТ ЕКСПЕРИМЕНТА ЛЮЛИН-5

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***Ключови думи**: космическа радиация, космическа радиационна дозиметрия, Международна Космическа Станция*

***Резюме:** От 2007г на борда на Международната Космическа Станция (МКС) с помощта на телескопа на заредени частици "Люлин-5" се изследват радиационните характеристики във сферичния тъканно-еквивалентен фантом в рамките на международния проект "Матрьошка-Р". От 27.12.2011г до 08.09.2013г бяха проведени измервания вътре и извън фантома в модула МИМ1 на МКС. В настоящата работа са представени резултатите за радиационните дози, получени в този период, и приноса в тях на галактическите космически лъчи и захванатите протони.*

Introduction

Humans are exposed to the impact of natural ionizing radiation at any time anywhere in outer space. As the ionizing radiation can induce a variety of harmful biological effects, it is necessary to quantitatively assess the level of exposure to it as a basis for estimating the radiation hazard during various manned space activities. A current manned space vehicle is the International Space Station (ISS) and monitoring the radiation environment in it is a task directly related to crew's health.

The radiation field in the ISS is complex, composed of galactic cosmic rays (GCR), trapped radiation of the Earth radiation belts, solar energetic particles (SEP), albedo particles from Earth's atmosphere and the secondary radiation produced in the shielding materials of the spacecraft and in human body [1].

The GCR are charged particles that originate from sources beyond our solar system. The energies of GCR particles range from several tens up to 10^{12} MeV.nucleon^{-1}. The GCR spectrum consists of 98% protons and heavier ions (baryon component) and 2% electrons and positrons (lepton component). Up to 1 GeV the flux and spectra of GCR particles are strongly influenced by the solar activity and hence show modulation that is anti-correlated with solar activity [2].

The biological impact of space radiation to humans depends strongly on the particle's linear energy transfer (LET) and is dominated by the high LET radiation. Especially important is the effect of the high energy heavy ion component of GCR (typically referred to as high Z and energy - HZE particles), possessing high LET and highly penetrating in human body, which provides them with a large potential for radiobiological damage [3]. The deep and prolonged minimum of the descent phase of Cycle 23 produced a very high flux of GCR, including a flux of iron ions nearly 20% higher than observed in the previous solar minima [4].

Another component of the incident radiation field at the ISS orbit are the trapped protons and electrons of the radiation belts. The trapped protons of the inner radiation belt have energies up to several hundreds of MeV and contribute a large fraction of the dose rates outside and inside the ISS. The trapped protons are encountered by LEO spacecraft in the region of the South Atlantic Anomaly (SAA). Although only about 5% of the mission time of the ISS is spent in the SAA, the astronauts may collect more than 50% of their total absorbed dose during this short time period [5, 6].

The electrons of the inner and outer radiation belts have energies up to a several MeV. These electrons are easily stopped before penetrating the spacecraft interior by the self-shielding of the spacecraft and are mainly of concern to an astronaut in a spacesuit during an EVA (Extra – Vehicular Activity) [7].

A sporadic radiation component at ISS orbit are the SEP. They consist of protons, electrons, helium ions, and HZE ions with energy ranging from a few tens of keV to GeV and the intensity can reach 10^4 cm^{-2} s^{-1} sr^{-1}. It is now widely agreed that SEPs come from two different sources with different acceleration mechanisms working: the flares themselves release impulsive events while the coronal mass ejection (CME) shocks produce gradual events [8]. Electrons with energies of ~0.5 to 1 MeV arrive at the Earth, usually traveling along interplanetary field lines, within tens of minutes to tens of hours. Protons with energies of 20 to 80 MeV arrive within a few to ~10 hours, although some high energy protons can arrive in as early as 20 minutes. SEP are relatively rare and occur most often during the solar maximum phase of the 11-year solar cycle.

Dose characteristics in LEO depend also on many other parameters such as the solar cycle phase, spacecraft orbit parameters, helio – and geophysical parameters.

For the estimation of the organ doses from the complex radiation field in the ISS, and thus the radiation risk, measurements in a model of the human body – the spherical tissue–equivalent phantom of the MATROSHKA-R international experiment have been conducted on the Russian segment of the ISS since 2004 [9]. The spherical tissue–equivalent phantom [10] is equipped with passive radiation detectors and active instruments for studies of the depth dose distribution at various sides of the organs of a human body exposed to cosmic radiation.

Liulin-5 [11] is an active instrument in the spherical phantom. The aim of this work is to present the results for dose rates and particle fluxes from the Liulin-5 experiment that concern measurements in and outside the phantom at the maximum of the 24th solar cycle.

Liulin-5 method and instrument

The Liulin-5 particle telescope consists of detector module and an electronic block (Fig.1-upper panel). While in the phantom the detector module of Liulin-5 is mounted inside the largest phantom's diameter channel (Fig.1 –bottom panel). More detailed description of Liulin-5 method and instrument can be found in [11]. The detector module of Liulin-5 contains three silicon detectors D1, D2 and D3 arranged as a telescope. The detectors axis is along the phantom's radius. The D1 detector is at 40 mm, D2 is at 60 mm and D3 is at 165 mm distance from the phantom's surface.

The position of D1 and D2 in the phantom corresponds approximately to the depth of the blood forming organs in human body, while D3 is placed very close to the phantom's centre. This

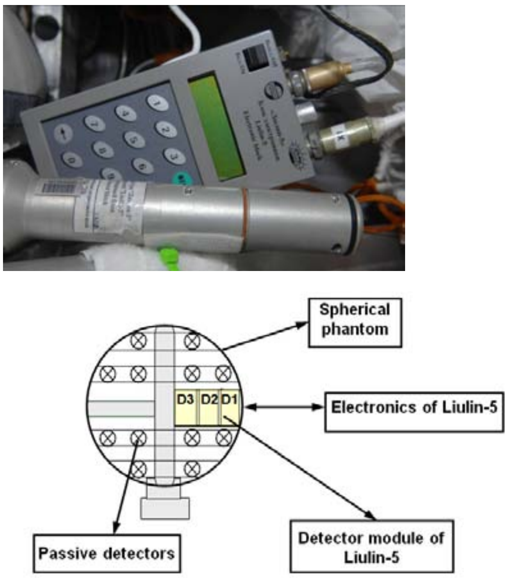


Fig. 1. Upper picture - the Liulin-5 detector module (front) and electronic module (back), located behind panel 205 in MIM1 module of ISS. Bottom-sketch of the detectors arrangement in the phantom.

arrangement allows measuring the dose-depth distribution along the sphere's radius.

The investigation of the local radiation environment in ISS by the Liulin–5 experiment envisages: i) measurement of the energy deposition spectrum, flux and dose rate, and absorbed dose D in each detector; ii) measurement of the LET spectrum in silicon, and then calculation of LET spectrum in water and Q, according to the Q(L) relationship given in ICRP60 [12], where L stays for LET. Q(L) is related functionally to the unrestricted LET of a given radiation, and is multiplied by the absorbed dose to derive the dose equivalent H.

Results and discussions

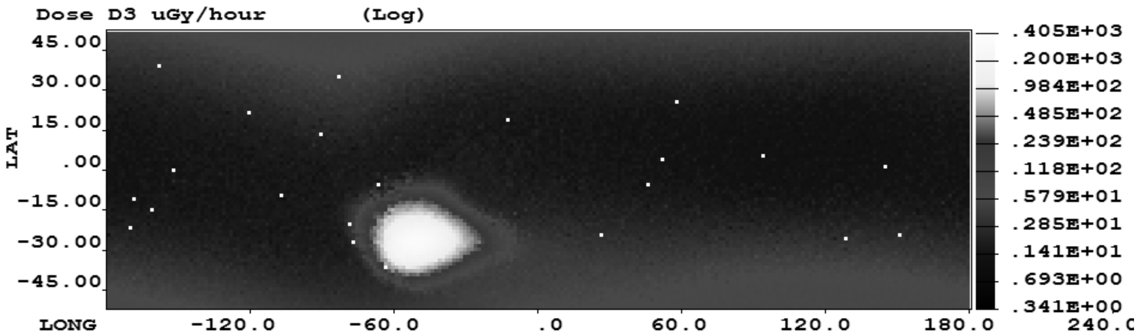
The results presented here concern the absorbed dose rates and dose equivalent values of GCR and trapped protons in SAA from measurements conducted inside and outside the phantom in the time period From 27 December 2011 to 8 September 2013. Data from measurements of SEP events in 2012- 2013 are subject of other publications [13]. From 27.12.2011 to 20.05.2012 the Liulin –5 detector module was mounted inside the phantom, located behind panel 206 in the MIM1 module of the RS of ISS. From 21.05.2012 to 30.08.2012 Liulin-5 was located outside the phantom again behind panel 206 and from 31.08.2012 to 11.09.2012 it was also outside the phantom, but behind panel 207 in MIM1. Since 12.09.2012 the Liulin-5 detector module is mounted again inside the phantom located in the MIM1 module behind panel 206.

Mapping the dose rate along the ISS orbit

The distribution of Liulin-5 absorbed dose rate measured near the centre of the phantom in the period 12.03.2012 - 08.09.2013 is presented in geographical and B-L coordinates in Fig.2. Maximum dose rates are obtained from trapped protons in SAA where they reached 405 µGy/h. Outside SAA doses from GCR are from about 10 µGy/h at high geographic latitudes and L>3 to values less than 1 µGy/h near the equator.

Absorbed dose and dose equivalent in and outside the phantom

The dose rate measured outside SAA near the centre of the phantom from January 2012 to March 2013 is presented in Fig. 3. These dose rates are from GCR, excluding the peak in March 2013 that is due to SEP event on 7-8 March 2012 (Semkova et al., 2013). The dose rates of GCR in the



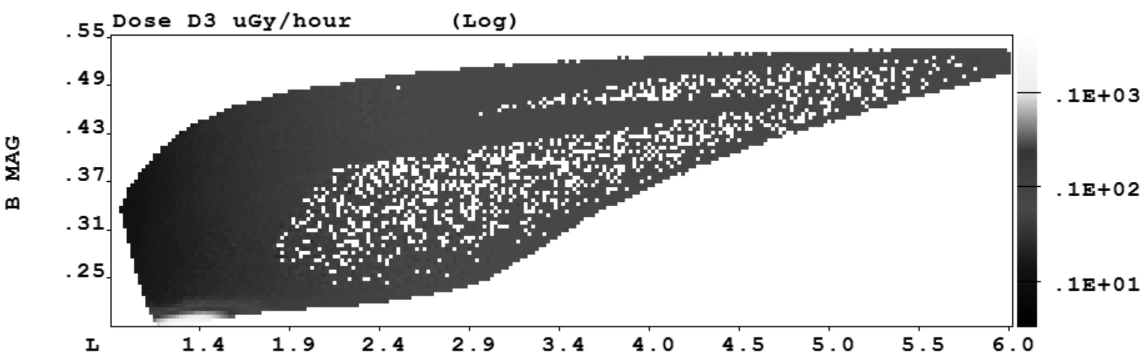


Fig. 2. Dose rate distribution at 165 mm depth in the phantom measured from 12.03.2012 to 8.09.2013. On the upper picture data is presented in geographical coordinates (longitude-latitude), on the bottom picture - in B-L coordinates. Dose rate is color-coded.

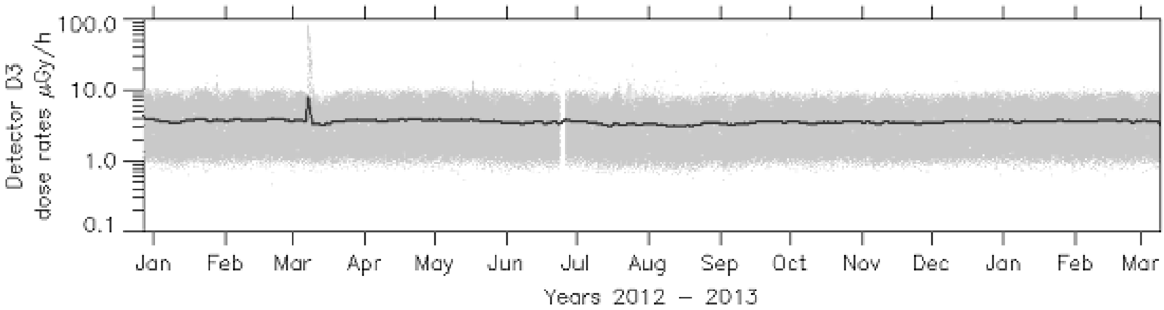


Fig. 3. Dose rate near the centre of the phantom measured from January 2012 to March 2013 outside SAA.

phantom are slightly higher than outside it (21.05-11.09.2012). That is probably due to contribution to the dose rates inside the phantom of secondary particles from interaction of primary GCR with the phantom's material. The average GCR dose rate is about 77 μGy·day^{-1}, that is about 12-15% less than the GCR dose rate, obtained by Liulin-5 experiment in PIRS1 module of ISS at the minimum of 23rd solar cycle [14].

In Fig.4. are presented the absorbed dose and dose equivalent rates measured inside the phantom at 40 mm depth (upper picture) and outside (lower picture). Data are averaged for periods of about 14 days. Due to the self-shielding of the phantom against trapped protons in SAA the doses_outside phantom (200–230 µGy/day) are higher than in it (120–150 µGy/day). The average dose equivalent rates are 220-470 µSv/day at 40 mm depth in the phantom and 400-540 µSv/day outside it.

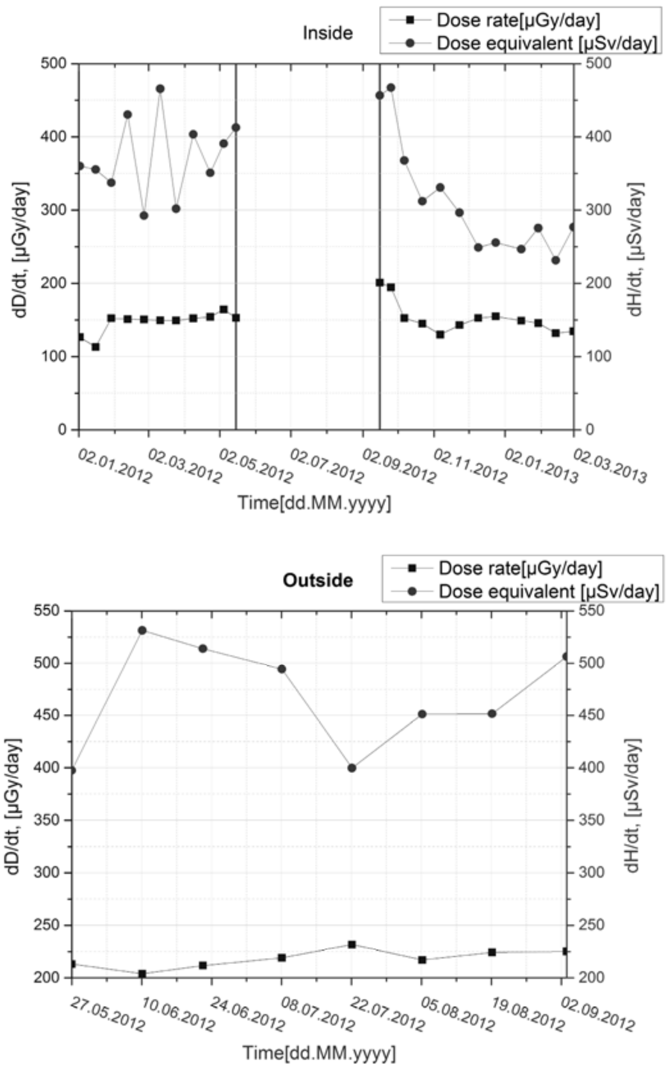


Fig. 4. Absorbed dose and dose equivalent rates measured inside the phantom at 40 mm depth (upper picture) and outside (lower picture).

Conclusion

Presented are the results for the dose and dose equivalent rates of GCR and trapped protons in SAA from measurements with Liulin-5 particle telescope conducted inside and outside the spherical tissue – equivalent phantom on ISS from 27 December 2011 to 8 September 2013.

The maximum dose rates are obtained from trapped protons in SAA where they reached 405 µGy/h near the phantom's centre. Outside SAA doses from GCR are from about 10 µGy/h at high geographic latitudes and L>3 to values less than 1 µGy/h near the equator.

The dose rates of GCR near the phantom's centre are slightly higher than outside the phantom. That is probably due to contribution to the dose rates inside the phantom of secondary particles from interaction of primary GCR with the phantom's material. The average GCR dose rate measured in MIM1 module of ISS at the maximum of 24th solar cycle is about 77 μGy·day^{-1}, that is about 12-15% less than the GCR dose rate, obtained by Liulin-5 experiment in PIRS1 module of ISS at the minimum of 23rd solar cycle.

Due to the self-shielding of the phantom against trapped protons in SAA the doses outside phantom (200–230 µGy/day) are higher than at 40 mm depth, corresponding to the shielding of blood forming organs in human body (120–150 µGy/day). The average dose equivalent rates are 220-470 µSv/day at 40 mm depth in the phantom and 400-540 µSv/day.

Acknowledgements

This work is partly supported by grant DID-02/8 from the National Science Fund and by the Agreement between BAS and RAS on fundamental space research. The authors are obliged to NIRS, Chiba-Japan for the organization of the calibrations of Liulin-5 instrument at HIMAC.

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