Space Shuttle drops down the SAA doses on ISS

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Long-term analysis of the data from 2 Bulgarian instruments on the International Space Station (ISS) shows that the docking of the Space Shuttle drops down the measured dose rates in the region of the South Atlantic Anomaly (SAA) by a factor of 2-3. Measurements either with the R3DE detector, which is outside the ISS at the EuTEF facility on the Columbus module behind a shielding of less than 0.45 g/cm^2, and by the 3 detectors of the Liulin-5 particle telescope, which are inside the Russian PEARS module in the spherical tissue equivalent phantom behind much heavier shielding demonstrate that effect. Simultaneously the estimated averaged incident energies of the incoming protons rise up from about 30 to 45 MeV. The effect is explained by the additional shielding against the SAA 30 to 150 MeV protons, provided by the 78 tons Shuttle to the instruments inside and outside of the ISS. The Galactic Cosmic Rays dose rates are practically not affected.

Instruments description

R3DE instrument

The R3DE (Radiation Risks Radiometer-Dosimeter (R3D) for the EXPOSE-E facility on the European Technological Exposure Facility (EuTEF) outside of the European Columbus module of ISS is a Liulin type miniature spectrometer-dosimeter with an additional 4 channel visible and UV spectrometer [1, 2] (Figure 1). Pulse high analysis technique is used for obtaining the deposited energy spectrum, which is further used for the calculation of the absorbed dose and flux in the silicon detector. The unit is managed by a specially developed firmware. An RS232 interface provide the transmission of the stored data to the EXPOSE-E facility. Liulin type instruments were calibrated with high energy fluxes of protons and heavy ions at different accelerators [3, 4]. The sensitivity was proved against neutrons and gamma radiation [5], which also allows monitoring of the natural background radiation. The instrument is a mutual development of STIL-BAS and Friedrich-Alexander-Universität, Department for Biology, Erlangen, Germany [6] in the frame of the ESA EXPOSE project led by DLR [6a].

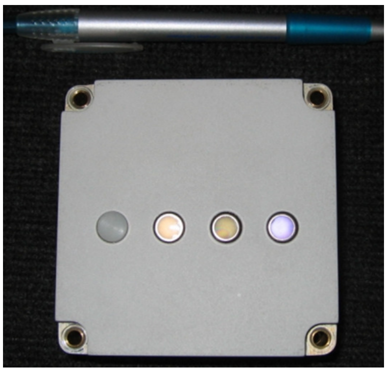

Fig.1. View of the R3DE instrument, which worked on the EuTEF platform of the European Columbus module of the ISS between February 2008 and September 2009. The 4 solar UV and visible radiations photodiodes are seen in the centre of the figure

The R3DE instrument worked between 20th of February 2008 and 5th of September 2009 with 10 seconds resolution behind less than 0.4 g.cm^{-2} shielding. This allows direct hits on the detector by electrons with energies higher than 0.78 and protons with energies higher than 15.8 MeV [7]. The surface of the detector is orientated perpendicularly to the "+Z" axis of the ISS.

Liulin-5 instrument

The Liulin-5 consists of two units: a detector module, placed inside the phantom and an electronic block outside (Figure 2). The detector module contains three silicon detectors, D1-D3, arranged as a telescope, and placed at different depths of the phantom, to measure the dose-depth distribution, and three charge-sensitive preamplifiers-shaping amplifiers.

Fig.2. View of the Liulin-5 instrument. In the left part is seen the electronic block, while in the right is the detector module. The first detector of the telescope is at the bottom of the figure, the second is in the middle where the black line is seen, the third is at the top

The thickness of the sensitive volume of each detector is 0.37 mm, and the area is 116.1 mm^2. Each detector records the amount of energy deposited in the detector. The detectors Dl and D2 operate in coincidence mode. If a particle enters the telescope within the 81.4^0-degree sensitivity cone, and it has enough energy to make it through both the Dl and D2 detectors, it is considered a coincident event. The data for this event are recorded, and used to define the linear energy transfer (LET).

The electronic block is mounted outside the phantom. It provides electric power to the detector module, controls the operation of the instrument, and accumulates the data from measurements in flash memory [8]. The investigation of the radiation environment in the phantom on ISS by Liulin–5 experiment envisages: i) measurement of the depth distributions of the energy deposition spectra, flux and dose rate, and absorbed dose, ii) measurement of the LET spectra in silicon. The LET spectra in silicon obtained are used for calculation of the LET spectra in water, the quality factors and the dose equivalent rates.

The instrument is built in collaboration between the Institute of Biomedical Problems - Moscow, Russia and the STIL-BAS. The Liulin-5 instrument was launched to the ISS in June 2007 and worked successfully till now (October 2009). It is a part of the international project MATROSHKA-R on ISS, which aimed to study the depth-dose distribution at the sites of critical organs of the human body, using a fully instrumented model of the human body - anthropomorphic (ESA–Facility MATROSHKA [9] (Reitz and Berger, 2006) and spherical tissue–equivalent (Russia) phantoms [10].

Data analysis

Long-term measurements of ISS radiation environment as by R3DE instrument

Figure 3 (upper panel) shows the results of R3DE measurements of the SAA dose rate in µGy h^{-1} for the time span between 1st of March 2008 and 6th of December 2008. The SAA doses are separated from all R3DE data by 2 simple requirements. The first one is that the dose rate be larger than 200 µGy h^{-1}, which exclude the Galactic cosmic rays (GCR) dose rates being usually below 50 µGy h^{-1}. The second one is that the dose to flux ratio has to be larger than 1 nGy cm^{2} part^{-1}. This requirement excludes the parts of orbits with relativistic electrons precipitations (REP), in which the dose–to-flux ratio is less than 1 nGy cm^{-2} part^{-1} [2, 11]. (More about the different radiation sources are seen at Figure 4.) The 3 patterns marked with filled but transparent rectangles and labelled as STS-123, 124 and 126 show the time when the 3 different missions of Space Shuttles were docked with the station. The labels in the upper part give the exact date, UT time of docking and undocking. One non-filled non-transparent rectangle shows the longest period with “No Data”. A few others are seen in the picture. The difference with the Shuttle troughs is that for “No Data” occasions blanks are seen in both panels. The points in the upper panel show the measured dose rates during one crossing of the SAA region. Because of large time differences in the X axes these dose rates are seen as bars between 200 µGy h^{-1} and the maximum observed in the SAA dose rate level.

The lower panel of Figure 3 shows the altitude where the doses are measured (bars). The data in both panels are plotted for all parts of orbits of the station where the dose rate is higher than 200 µGy h^{-1}. That is why the altitudes in the lower panel are not seen as points but as bars between the beginning and end altitudes. The relatively low dose rates at the left side of the figure are connected with ISS altitudes in the range 350-365 km. The increase of the station altitude up to 365-375 km after 21st of June 2008 is connected with an expected increase of the SAA dose rate in average with 10.4 µGy h^{-1}.

The main feature seen in Figure 1 is that during the Space Shuttle docking time SAA doses fall below the level of more

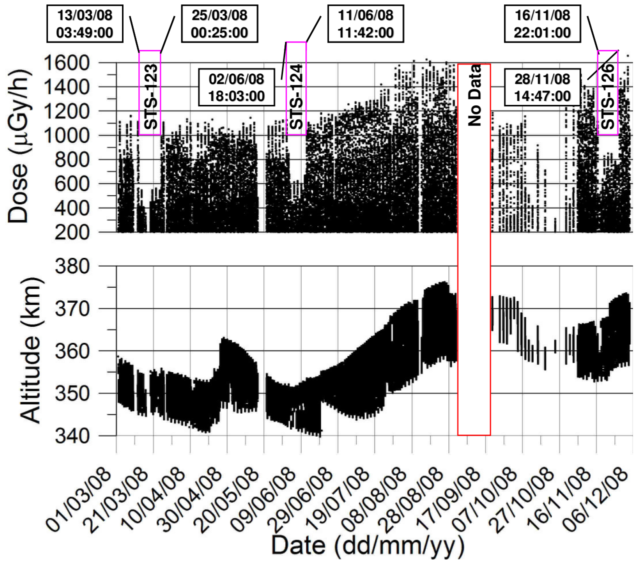

Fig.3. Long-term variations of the dose rates higher than 200 µGy h^{-1} measured by R3DE

than 1000 µGy h^{-1} down by 600 µGy h^{-1} and reach an average level of 500 µGy h^{-1} for the STS-119 and 124 missions. For the STS-126 the drop down is also of 600 µGy h^{-1} but from an average level of 1400 µGy h^{-1}.

R3DE Latitudinal distribution of the ISS radiation environment components

Figure 4 presents the latitudinal distribution in L-values [12, 13] of the doses along the ISS orbit. On the X axis the L-value is plotted. On Y axis the dose rate measured by the R3DE instrument in 3 panels is plotted. The 3 panels cover data from 5th to 31st of March 2008.

On the bottom panel the 5-12 March data are plotted. This is a period before the docking of STS-119. Three different radiation sources are easy to distinguish from the data. The major amount of measurements is concentrated in the GCR points, which are seen as area with many points in the lower part of the panels in L-values range between 0.9 and 6.2. The covered dosed rate range is between 0.03 and 20-25 µGy h^{-1}. The lowest rates are close to the magnetic equator, while the highest are at high latitudes equatorwards from both magnetic poles.

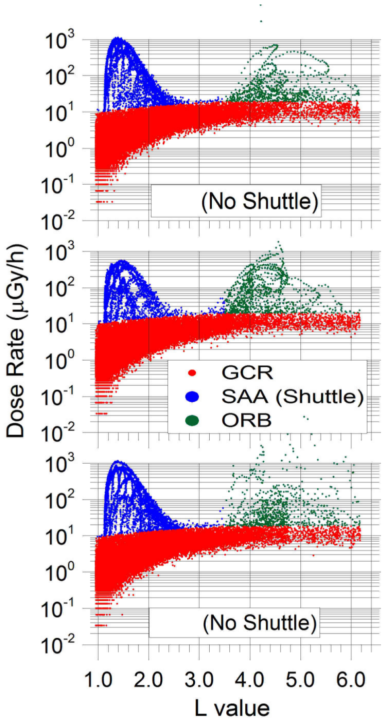

Fig.4. Invariant latitude profile of the ISS radiation environment

The measured by R3DE GCR dose rates in the whole invariant latitudes profile show a small decrease during the STS-119 docking period in March 2008. For example, the average dose for the period 19-24 March during the Shuttle docking at L=5 (the real diapason is 4.9<L<5.1) is 14.13 μGy h^{-1}. For the period 04-08 April 2008 (after the Shuttle visit) the average dose at L=5 rises up to 14.6 μGy h^{-1}. This tendency is realized in reverse to the GCR Oulu neutron monitor measurements http://cosmicrays.oulu.fi/, with a mean value for the period 19-24 March of 6678 corrected count rate per minute, while 6627 for the period 04-08 April 2008 is 6627. Similar peculiarities are observed during the STS-126 docking time. GCR dose rates before the docking of the Shuttle (11-17 November 2008) have an average value of 16 μGy h^{-1}, while with Shuttle (19-24 November 2008) the dose rates fall to 13.14 μGy h^{-1}. This happens also in reverse to the GCR Oulu neutron monitor measurements. In the first period the corrected count rate per minute is 6722, while for the second it is 6772.

Another attempt to compare the GCR dose rates at L=5 for the time after the docking STS-126 shows dramatically low dose rates of 10.8 μGy h^{-1} in the period 2-8 December 2008 when the average Oulu neutron monitor count rate is 6772 per minute. This result show that the question of the influence of the GCR dose rates at the Station by the Shuttle is still open and that further investigations are needed.

The second source are the protons in the inner radiation belt (RB), which are situated as a large maximum in the upper-left part of the panels. They cover the range in L-values between 1.2 and 2.6. This area is usually denoted as the South Atlantic anomaly (SAA) region. The dose rates in the SAA region vary between 10-15 and 1130 μGy h^{-1}. The structure seen inside of the SAA maximum is connected with the different way of crossing of the anomaly by ISS along the orbit. The wide peaks, which cover almost the whole L range, are measured during the descending parts of the orbits of the station. The maximum dose rates of about 1130 μGy h^{-1} are observed at these descending orbits. The ascending parts of the orbits are seen as short peaks and the maximum dose rates there are about 1000 μGy h^{-1}.

The wide maximum in L-values between 3.5 and 6.2 is connected with the observations of rare sporadic Relativistic electrons precipitations (REP) generated in the outer RB [11, 14]. Here the absolute maximum of dose rate value of 19194.6 μGy h^{-1} is reached. This large dose is deposited in 10 seconds by 167264 electrons with energies above 0.8 MeV. The average maximum of the REP tends to be close to the L-value of 4.6. The higher density of the points for L-value below 4.6 is explained with the asymmetries in the magnetic field in the Northern and Southern hemisphere. Because the larger distance of the magnetic pole in the Southern hemisphere than in the Northern the observed L-values in the Northern hemisphere are with a maximum L value of 4.7. In the Southern hemisphere the maximum L-value of 6.2 is reached.

The middle panel (dose rate distribution) shows very similar features as the lower one with the exception that the SAA maximum is reaching maximum values of 530 μGy h^{-1} again at the descending orbits. The effect is explained by the additional shielding against the SAA 30 to 150 MeV protons, provided by the 78-tons Shuttle, which during the period 13-25 March is docked with the ISS.

The upper panel distribution is accumulated after the visit of the Space shuttle and is very similar to the lower panel.

Liulin-5 data

Figure 5 presents the dose rates measured by the 3 detectors of the Liulin-5 instrument from 7^{th} to 31^{st} of March

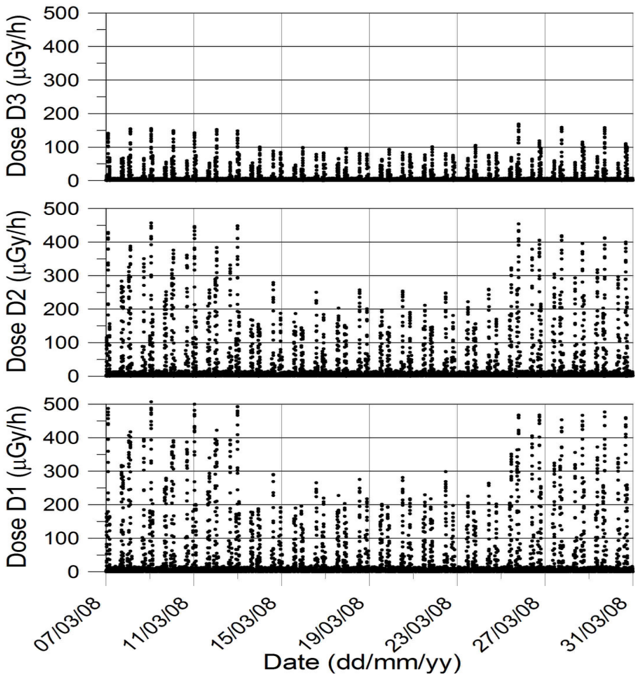

Fig.5. The 3 panels present the data from the 3 detectors of the Liulin-5 instrument

2008. The lower panel presents the measured doses in the first detector of the telescope, which is closer to the Phantom surface and respectively at lower shielding. The middle panel presents the data from the second detector, while in the upper panel are the data from the third (most shielded) detector. As is expected, the maximum dose rates are seen in the bottom panel, while the minima are in the top panel. Even in the less shielded first detector the dose rates are about twice lower than the ones observed at the same time by the R3DE instrument and presented at Figure 3. This is because even the less shielded direction of this detector is behind about 5 g cm^{-2} [15], which is about 12 times heavier shielded than the R3DE detector (0.4 g cm^{-2}).

Another important feature seen in the three panels is the decrease of the doses after 13^{th} of March 2008 and increase again after 25^{th} of March. The exact moments are 03:49:00 UT on 13^{th} of March and 00:25:00 on 25^{th} of March. These moments are connected with the docking and undocking, respectively, of STS-119 to the ISS. The decrease has different values in the three detectors. In the first detector (bottom panel) the dose rate decreased from about 500 μGy h^{-1} to 300 μGy h^{-1}, while in the third detector the doses fall from 150 to 100 μGy h^{-1}.

Because of very low time resolution in Figure 5 each crossings of the SAA anomaly is presented by a pair of 2 bars. The first one corresponds to the ascending orbit, while the second one to the descending. The differences are produced by the east-west asymmetries of the proton fluxes in the region of the SAA [15-17]. Looking more precisely on the data in the bottom panel we see that after 13th of March the first (ascending) maximum starts to be larger than the second – descending. This is not connected with the arrival of the Shuttle but with a change of the orientation of ISS. According to Chernikh et al. [15 (Fig.12)] the station was rotated at 180° from its usual orientation when the US laboratory module is against the vector of the station velocity toward the opposite one. This maneuver rotates the ascending and descending maxima in the first and second detectors of Liulin-5 but not in the third (most shielded) detector. As is seen from the top panel of Figure 5 the ascending maximum is always smaller than the descending one. R3DE data show a similar behavior as is seen in Figure 4. The question how the heaviest shielded third detector of Liulin-5 and the practically not shielded detector of R3DE are not affected by the rotation of ISS will be studied in a future paper.

Discussion

The decreases of the dose rates, observed by the R3DE and Liulin-5 instruments, when the Space Shuttle is docked with the station can be explained by the additional shielding against the SAA 30 to 150 MeV proton fluxes, provided by the 78-tons Shuttle to the instruments inside and outside of the ISS. Qualitatively this is shown on Figure 6. The large and heavy body of the Shuttle covers a wide angle of view (shown with light and heavy and dashed lines) of the R3DE and Liulin-5 instruments. Exact quantitative modeling of the ISS and Shuttle doses are in process and the results will be presented in future.

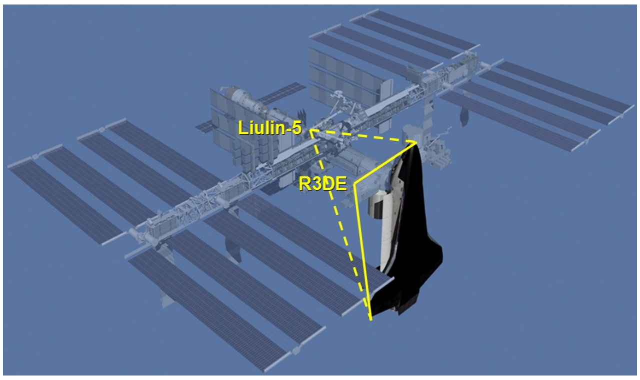

Fig.6. Sketch of the configuration of ISS with the docked Space shuttle.

Results similar to the ones presented by us were shown at the 13th WRMISS workshop by Semones [18] and Benghin [19] in the daily average dose rate data of the Tissue equivalent proportional counter TEPC located inside the Columbus module and in the ratio of the dose rates of the DB-8#3 and DB-8#2 detectors inside of the service module of ISS. The observed decreases were partially associated with the docking of the Shuttle with the ISS, but the general conclusion for the effect were not presented.

Acknowledgements

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