The DOSIS and DOSIS 3D project on-board the ISS – Current status and scientific overview

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Abstract— **The radiation environment encountered in space differs in nature from that on Earth, with contributions of protons and high energetic ions up to iron, resulting in radiation levels far exceeding the ones present on Earth and what is allowed for occupational radiation workers. Accurate knowledge of the physical characteristics of the space radiation field in dependence on the solar activity, the orbital parameters and the different shielding configurations of the International Space Station (ISS) is therefore important. For the investigation of the spatial and temporal distribution of the radiation field inside the European Columbus module the experiment "Dose Distribution inside the ISS" (DOSIS), under the project and science lead of DLR, was launched in July 2009 with STS-127 to the ISS. The DOSIS experiment consists of a combination of "Passive Detector Packages" (PDP) distributed at eleven locations inside Columbus for the measurement of the spatial variation of the radiation field and two active DOSimetry TELescope´s (DOSTEL) with a the DOSTEL Data and Power Unit (DDPU) in a dedicated Nomex pouch mounted at a fixed location beneath the EPM rack for the measurement of the temporal variation of the radiation field parameters. The DOSIS experiment suite measured during the lowest solar minimum conditions in the space age from July 2009 to June 2011. In July 2011 the active hardware was transferred to ground for refurbishment and preparation for the follow up DOSIS 3D experiment. The hardware for DOSIS 3D was launched with Soyuz 30S in May 2012. The PDPs are replaced with each even number Soyuz flight starting with Soyuz 30S and with each odd number Soyuz flight starting with Soyuz 45S. Data from the active detectors is transferred to ground via the EPM rack which is activated once a month for this action. This paper will give an overview of the DOSIS and DOSIS 3D experiment and focus on the results from the passive radiation detectors from the DOSIS 3D experiment (2012 - 2016) in comparison to the data of the DOSIS experiment (2009 - 2011), and what we can learn from that for the future planned interplanetary space missions.**

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1. INTRODUCTION

The radiation field in free space is complex and consists of Galactic Cosmic Rays (GCR), as well as protons due to sporadic Solar Particle Events (SPE) [1]. These two sources contribute to the radiation for personnel inside and outside space vehicles, e.g. on the way to Mars, and can lead to dose equivalent values only from GCR exposure of up to 1.84 mSv/day [2]. In Low Earth Orbit (LEO) a third contribution to human radiation exposure is given by the trapped particles in the Earth radiation belts (Van Allen belts) while the International Space Station (ISS) crosses the South Atlantic Anomaly (SAA) [3]. Inside a space vehicle, there are also neutrons created by the interactions of the GCR and SPE with the hull and materials of the space craft, as well the bodies of the space station crew. To secure the safety and minimize the radiation risks for the crew members on planned future long duration space missions, it is essential to be able to simulate the radiation environment in the planned future space craft and test the effect of different shielding materials and configurations. In order to test and benchmark the existing radiation transport models, measurements on the ISS are of great importance.

The radiation environment onboard the ISS is being monitored since the beginning of the ISS era with various active and passive radiation detector systems (see e.g. reviews in: [4], [5] and [6]) aiming for exact area monitoring within [7] and outside the ISS [8]. Furthermore various experiments aiming for the determination of the effective dose equivalent using phantoms for the improvement of radiation risk estimations have been performed (see for example: [9], [10] and [11]). In addition, passive radiation detector systems have been used as operational personal radiation detectors of the astronauts and cosmonauts [12]. The DOSIS 3D experiment currently performed onboard the ISS is aiming to improve our understanding of the radiation environment onboard the ISS and provide a set of data which can be utilized by the radiation research community for benchmarking of radiation models and transport codes, as

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well providing input to build up a real 3D computer model of the radiation environment inside the ISS.

The paper is intended to provide an overview of the DOSIS and DOSIS 3D experiment and show exemplary data [13].

2. THE DOSIS AND DOSIS 3D EXPERIMENTS

The aim of the DOSIS (2009 – 2011) and the DOSIS a 3D (2012 - ongoing) experiment was and is to measure the radiation environment within the European Columbus Laboratory of the ISS (see Fig. 1).

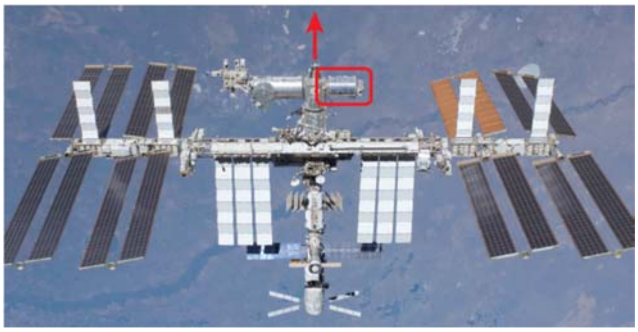

Figure. 1. The International Space Station (ISS) (Picture taken by STS-134 crew member on the space shuttle Endeavour, 29 May 2011) with the European Columbus Laboratory (in red) and the ISS flight direction (red arrow) Source: NASA.

The measurements are performed with passive radiation detectors mounted at eleven fixed locations within Columbus for the determination of the spatial distribution and long term temporal evolution of the radiation field parameters, and two active radiation detectors mounted at a fixed position inside Columbus for the determination of the temporal variation of the radiation field parameters. The passive detectors consist on so called Passive Detector Packages (PDP´s) built up of thermoluminescence (TL), optical luminescence (OSL) detectors and nuclear track etch detectors (CR-39), which are put together in relevant detector holders and sewed into Nomex Bags. These detector packages need to be returned to Earth for evaluation in the laboratories of the participating partners, and they will only provide integrated values of the dose received during their exposure.

The active part of the DOSIS & DOSIS 3D hardware consists of two silicon detector telescopes (DOSTEL-1 and DOSTEL-2) looking in flight direction (DOSTEL-1) and perpendicular to the ISS flight direction (DOSTEL-2). The two instruments are connected over the so called DOSTEL Data and Power Unit (DDPU) and mounted in a Nomex Box, called the DOSIS-MAIN-BOX at a fixed position beneath the EPM rack. The DOSIS-MAIN-BOX is connected via a NASA 16V Power Brick to an SUP outlet for the provision of the power to the instruments, and they can therefore provide near real time information about the radiation field parameters. Data connection is done via the EPM LAN Interface at the upper right part of the EPM Facility. The scientific and housekeeping data are downloaded by the EPM rack via Ethernet connection with a nominal period of four weeks.

Figure 2 provides a “Fish Eye View” of the relevant detector locations, thereby showing that the locations are chosen in a way to enable a 3D dose distribution profile over the whole Columbus Laboratory. In Figure 2, the flight direction is also shown and it can be seen that five of the PDP´s are located in forward direction while five of the PDP´s are mounted in the backward direction of Columbus. In addition PDP #X (so called Triple PDP) is mounted close to the active radiation detectors beneath the EPM Module thereby also being positioned in backward direction.

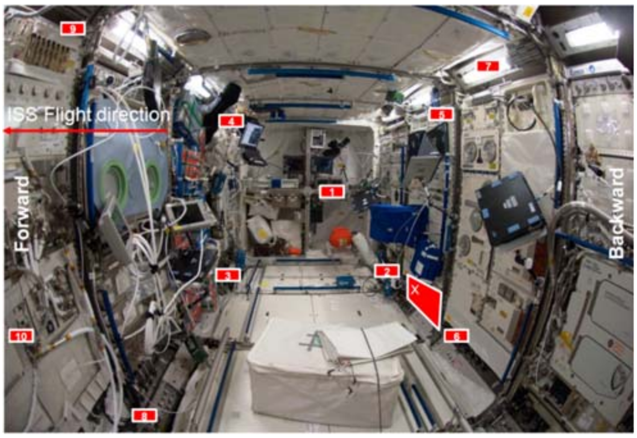

Figure. 2. The positions of the PDP´s within the Columbus Laboratory of the ISS. PDP #3, 4, 8, 9 and 10 are positioned in forward and PDP # 1, 2, 5, 6 and 7 in backward Columbus position. The eleventh PDP (X) is positioned at the big red rectangle beneath EPM attached to the DOSIS-MAIN-BOX Source: NASA/ESA.

The long term data gathered within the two experiments so far enables to see variations of the radiation environment due to changes in solar activity as well as due to altitude changes of the ISS.

3. DETECTOR SYSTEMS

The passive detector systems used within DOSIS and DOSIS 3D are thermoluminescence (TL), optically stimulated luminescence (OSLD) and nuclear track etch detectors. The active detectors are Dosimetry Telescope (DOSTEL) detectors [14], [15], [16], [17]. Passive detector systems have been used since the Mercury missions [18] and especially the combination of luminescence detector with nuclear track etch detectors is currently widely applied onboard the ISS since it allows not only the determination of the absorbed dose, but also the dose equivalent in combining these two detector systems (see for example: [19]). Active silicon detector systems are commonly used onboard the ISS and offer therefore good baseline data for inter-comparison purposes. The DOSTEL are based on two passivated implanted planar silicon (PIPS) detectors each with a thickness of 315 µm and an area of 6.93 cm^2 arranged in a telescope geometry. The detectors are mounted at a distance of 15 mm yielding a telescope with a geometric factor of 824 mm^2 sr for particles in coincidence mode. With this detector configuration, the DOSTEL measures count rates and dose rates of radiation hitting a detector ("dose measurement") and coincidental hits in the two detectors to limit the path length in the detectors and thereby derive information about the Linear Energy Transfer (LET) ("telescope" or "LET" measurements). Based on the measured data DOSTEL provides absorbed dose and dose equivalent values. Due to the fact, that two DOSTEL instruments are mounted in perpendicular positions, also information about the directionality of the radiation field inside Columbus can be determined.

4. Results and Discussion

Within the eight passive experiment phases of the DOSIS (Phase 1 and 2) and DOSIS 3D (Phase 1 to Phase 6), in the years 2009 – 2015, a tremendous amount of data has been gathered by the research groups participating in the experiments.

Figure 3 provides an overview of the relevant absorbed dose rate values measured by ATI, IFJ, SCK•CEN, DLR, MTA EK, NPI, NASA/SRAG and OSU for all applied TL/OSL materials during DOSIS D3 Phase 2 (October 2012 – March 2013). Figure 3 combines the datasets for ^{6}LiF:Mg,Ti; ^{7}LiF:Mg,Ti; CaF_2:Tm; ^{Nat}LiF:Mg,Ti; ^{6}LiF:Mg,Cu,P; ^{7}LiF:Mg,Cu,P; Al_2O_3:C (OSL); Al_2O_3:C (TLD) and $CaSO_4$:Dy in several subplots, providing at the same time also the comparison of the relevant data for each research group working with the relevant detector material. It is apparent that the data obtained by different groups with the same detector type agree quite well: in almost all cases the measured absorbed dose rates agree within the statistical uncertainties. At the same time there are substantial differences between absorbed doses measured with various detector materials. One reason for this difference lies in the distinct relative OSL/TL-efficiency to heavy charged particles (protons, helium up to iron) which constitute a large portion of the radiation environment onboard the ISS.

With the DOSTEL instrument, due to its active measurements, one is able to distinguish between contributions from GCR and SAA to the total absorbed dose. For example during the Phase 2 of the DOSIS experiment at the end of 2009 the average DOSTEL-1 absorbed dose rate accounted to 234 ± 18 µGy/day with contributions from GCR of 150 µGy/day and a contribution from the in average 4 – 6 daily SAA crossings of 84 µGy/day. For DOSIS 3D Phase 1 in 2012 with the increase in ISS altitude (see also Figure 4) the daily absorbed dose values account to 286 ± 25 µGy/day with contributions from GCR of 145 µGy/day and a contribution from the SAA crossings of 141 µGy/day. With this the SAA contribution increased by around 75% due to the changes in ISS altitude. In terms of comparison with other active radiation detectors onboard the ISS one can state, that the absorbed dose rates measured with the DOSTEL-1 instruments are in line with data provided by the Russian DB-8 instrument located in the Russian Zvezda Module of the ISS [20] taking into account the different shielding thicknesses the four DB-8 units have inside the Russian part of the ISS.

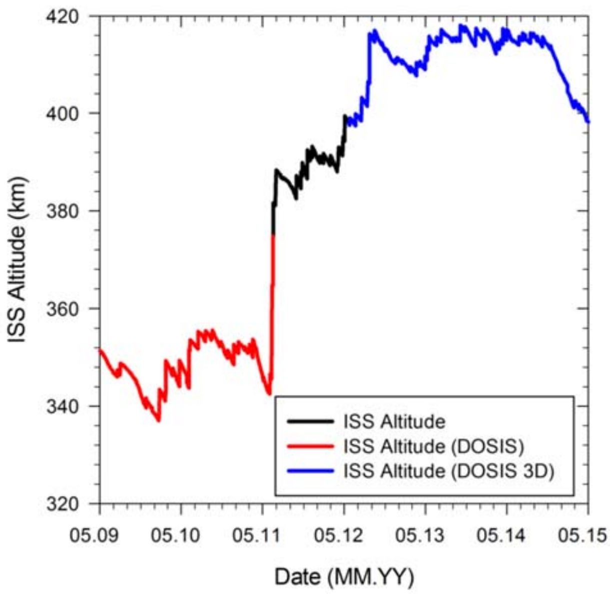

Figure 4. The average ISS altitude over the time of the DOSIS (red) and DOSIS 3D (blue) experiments [13].

One other parameter influencing the radiation environment in LEO and the radiation load inside the ISS is the solar cyle. Due to enhanced deflection by the interplanetary magnetic field, increasing solar activity causes decreasing dose contribution from Galactic Cosmic Rays as well as for the protons in the South Atlantic Anomaly. To illustrate this Figure 5 shows the Oulu neutron monitor count rate (http://cosmicrays.oulu.fi) for the DOSIS (in red) and DOSIS 3D (in blue) experiment timeframe. Whereas DOSIS (2009 – 2011) was performed in the deepest solar minimum conditions of the space age, especially in the year 2009, DOSIS 3D started in 2012 with already increasing solar activity and was running during solar maximum conditions in the years 2013 and 2014.

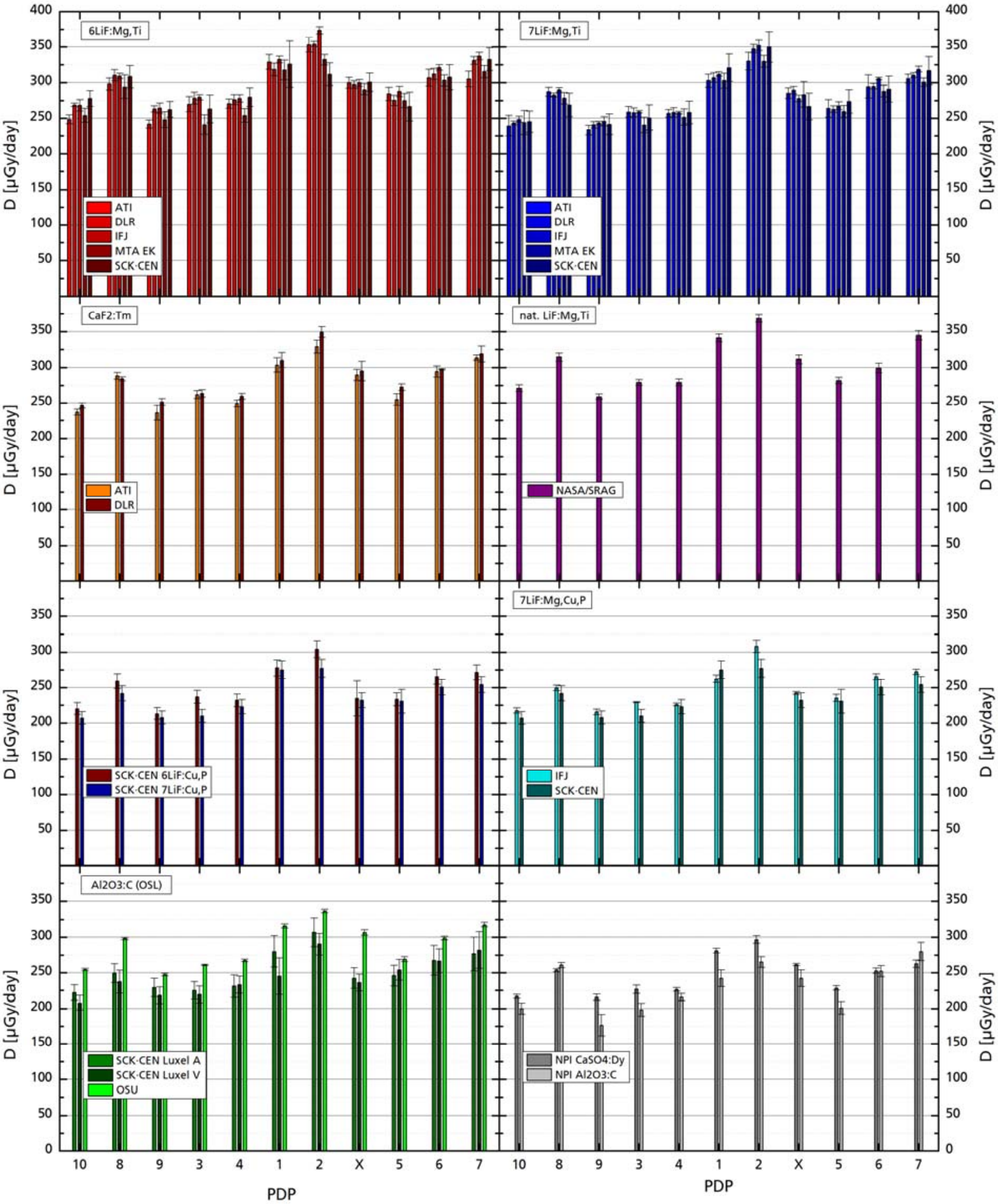

Figure 3. Summary of results for all TLD/OSL detector materials for the DOSIS 3D Phase 2 (October 2012 – March 2013) [13]. The PDP numbering for the horizontal axes is based on the locations of the PDP´s in the Columbus Laboratory, starting with location #10 at the left entry of Columbus following the locations on the Columbus forward side up to PDP #1 and coming back the Columbus backward side ending at PDP position #7.

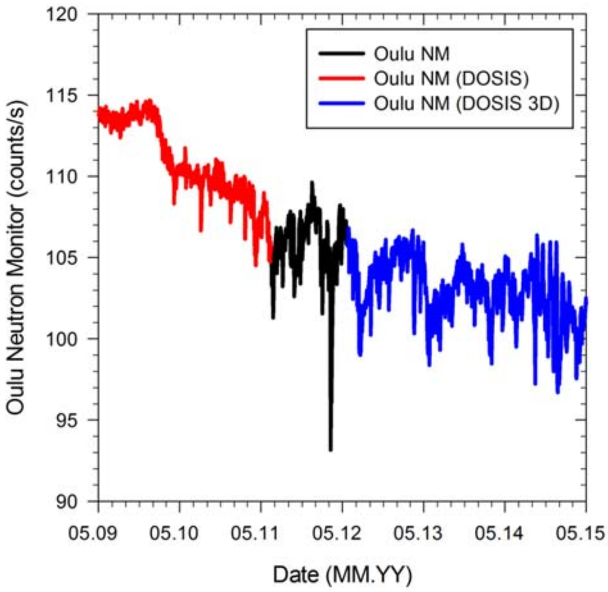

Figure. 5. The Oulu neutron monitor count rate over the time of the DOSIS (red) and DOSIS 3D (blue) experiments [13].

5. Summary and Conclusion

In the frame of the DOSIS (2009 – 2011), and the still ongoing DOSIS 3D (2012 –), experiment the spatial and temporal variation of the radiation environment in the European Columbus Laboratory onboard the ISS has been and still is being mapped with a variety of passive and active radiation detectors. The passive radiation detectors (TLD and OSLD) enabled the determination of the variation of the, over time integrated, absorbed dose rates at eleven positions inside Columbus. The data measured with these passive radiation detectors showed that the absorbed dose values inside the Columbus Laboratory follow a pattern, based on the local shielding configuration of the radiation detectors, with minimum dose values observed in the year 2010 of 195 to 270 μGy/day and maximum values observed in the year 2012 with values ranging from 260 to 360 μGy/day. The absorbed dose is modulated by (a) the variation in solar activity and (b) the changes in ISS altitude. In summary the data inside Columbus shows variations of up to 50%. A comparison with data gathered by the active DOSTEL-1 instrument over the mission phases showed a good agreement of the absorbed dose values measured by the active systems and data from the passive ^{7}LiF:Mg,Ti detectors. The database generated up to now will be further expanded including data from the combination of the passive TLD/OSLD systems with the Nuclear Track Etch Detectors and further comparison with the active systems.

Acknowledgments

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