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Onboard cross-calibration of the Pille-ISS Detector System and measurement of radiation shielding effect of the water filled protective curtain in the ISS crew cabin

P. Szántó [a, *], I. Apáthy [a], S. Deme [a], A. Hirn [a], I.V. Nikolaev [c], T. Pázmándi [a], V.A. Shurshakov [b], R.V. Tolochek [b], E.N. Yarmanova [b]

[a] Hungarian Academy of Sciences Center for Energy Research, Budapest, Hungary
[b] Institute of Biomedical Problems, Russian Academy of Sciences, Moscow, Russia
[c] Rocket and Space Corporation, Energia, Moscow Region, Russia

HIGHLIGHTS

- The dose level in the ISS Zvezda crew quarters is higher than the average dose level in the module.
- A shielding made of hygienic wipes and towels was set up onboard as additional protection.
- Onboard cross calibration of the Pille-ISS space dosimeter (TL) system was performed.
- The shielding effect of the protective curtain in terms of absorbed dose was measured with the onboard Pille system.
- The shielding effect of the protective water curtain is approximately 24 ± 9% in absorbed dose.

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ABSTRACT

As a preparation for long duration space missions it is important to determine and minimize the impact of space radiation on human health. One of the methods to diminish the radiation burden is using an additional local shielding in the places where the crewmembers can stay for longer time. To increase the crew cabin shielding a special protective curtain was designed and delivered to ISS in 2010 containing four layers of hygienic wipes and towels providing an additional shielding thickness of about 8 g/cm^2 water-equivalent matter. The radiation shielding effect of the protective curtain, in terms of absorbed dose, was measured with the thermoluminescent Pille-ISS Detector System. In order to verify the reliability of the Pille system an onboard cross-calibration was also performed. The measurement proved that potentially 25% reduction of the absorbed dose rate in the crew cabin can be achieved, that results in 8% (~16 μGy/day) decrease of the total absorbed dose to the crew, assuming that they spend 8 h in the crew cabin a day.

1. Introduction

Concerns about the biological effects of space radiation are increasing rapidly due to the perspective of long-duration manned space missions, both in relation to the International Space Station (ISS) and to the planned manned interplanetary missions to Mars. As a preparation for these long duration space missions it is important to mitigate the impact of space radiation on human health in order to secure the radiation safety of the spacecraft crewmembers and minimize their risks. One of the methods to diminish the radiation loads is using an additional local shielding in the places where the crewmembers can stay for longer time. However, an additional shielding means an extra cost to deliver the extra mass to the space station and to spend the crew time for the shielding installation. As usually in such cases the ALARA (As Low as Reasonably Achievable) principle should be applied together with cost-benefits analysis.

The ISS Russian crew quarters are known to be less shielded from space radiation as compared with the neighbouring compartments. The outer wall of the cabin is only 1.5 g/cm^2 aluminium

* Corresponding author.
E-mail address: szanto.peter@energia.mta.hu (P. Szántó).

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shielding. Based on Pille-ISS Thermoluminescent Dosimeter System (Pille) measurements in 2007 and 2009 the dose rates at the sleeping place of the ISS crewmembers are 35% higher than the average dose rate in the Service Module (SM), Zvezda of the station (Fig. 1). Since the astronauts spend at least 30% of their time on the sleeping place, controlling the dose rates there is necessary (Apathy et al., 2007).

Nevertheless, a reduction in the absorbed dose rate on board is not sufficient on its own to mitigate radiation risks. Besides the physical dose the LET (Linear Energy Transfer)–dependent quality of the cosmic radiation as well as the sensitivity of the different organs to the radiation are also important in radiation risk assessment and so the quantities dose equivalent and effective dose equivalent are preferably applied. With the Pille system (and TL detectors in general) reduction in the absorbed dose rates can be studied. Since an increase in the biological effectiveness due to low energy secondary particles might (over)compensate the decrease in dose rates, and so it might result in increased radiation risk, measurements and analysis of the radiation in terms of LET spectrum is also necessary. A thicker shielding usually increases the effective dose equivalent from un-trapped Galactic Cosmic Rays, whereas it decreases that from the trapped radiation (Wilson et al., December 1991).

2. Experiment

To increase the crew cabin shielding a special protective curtain was designed and then delivered to ISS in 2010. The hygienic wipes and towels containing water are stored in the protective curtain in 3 segments and 4 layers thus providing an additional shielding thickness of about 8 g/cm^2 water-equivalent matter. Total mass of the curtain with wipes and towels is 67 kg with dimensions of $10.0 \times 43.6 \times 50.5$ cm^3, $10.0 \times 65.8 \times 63.2$ cm^3, and $10.0 \times 71.9 \times 60.0$ cm^3, from upper to bottom panel. The protective curtain was installed along the wall of the starboard crew cabin. To study the radiation shielding effect 12 passive detector packages with thermoluminescent detectors (TLD) and solid state track detectors (SSTD) are used regularly; their positions are indicated with #1–#12 in the paper (see Fig. 2).

Pille dosimeters were exposed at Locations #6, #7, #9, #10, #11, and #12. The detector IDs of the Pille dosimeters exposed are shown in Table 1.

3. Instrumentation

Pille reader is located on board the ISS Zvezda module and has been continuously providing dose data since November 2003 as part of the service dosimeter system in the Russian segment. Besides EVA (Extra-Vehicular Activity) and dose monitoring measurements, the dose map of the Zvezda module is measured monthly at 6–10 measuring points.

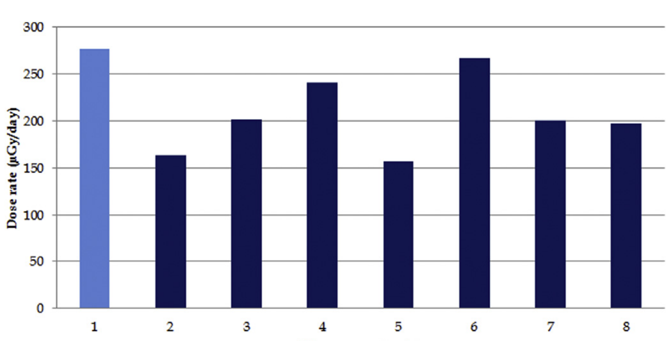

Fig. 1. Pille dose map from the Simonyi 1 experiment, 2007. Apr. 11–18. Dosimeter locations: 1: The sleeping place of space tourist Charles Simonyi; 2: SM right-side Panel 410 at detector DB-8 No.1; 3: SM left-side Panel 244 at detector DB-8 No.2; 4: SM right-side Panel 447 at detector DB-8 No.5; 2: SM right-side Panel 435 at detector DB-8 No.4; 6: SM Cabin of the right deck, left to the window; 7: SM Cabin of the left deck, right to the window; 8: SM floor Panel 111 at window No.6, floor.

The development of the Pille thermoluminescent dosimeter system started in the Hungarian Academy of Sciences Centre for Energy Research (MTA EK, the former KFKI AEKI) in the 1970s. The aim of the development was to invent a small, compact, space qualified TL reader device suitable for on-board evaluation of TL dosimeters (Fehér et al., 1981). Previous versions of the Pille system were on board all space stations orbiting the Earth since Salyut-6 in 1980. The latest version, the Pille-ISS consisting of one reader device and 12 dosimeters has been the service dosimeter system of the Russian Zvezda module of the ISS since 2003. Since that time more than 30,000 TL read-outs have been carried out providing monthly dose data at seven points on the ISS, personal dose data during EVAs and dose monitoring data with 90-min time resolution.

The Pille TL dosimeter contains $CaSO_4$:Dy TL material produced by the Budapest University of Technology. The TL material is laminated to the surface of a resistive, electrically heated metal plate inside a vacuum bulb made of glass. The dosimeter also contains a memory chip that stores identification data and individual calibration parameters of the device such as TL sensitivity, TL glow curve integration parameters or the time of the last read-out. Before flight the $CaSO_4$:Dy TLD bulbs are calibrated with a standard ^{137}Cs source beam. Only those bulbs are selected for which the reproducibility is within an accuracy of 5%. Taking into account the LET-dependent dose response of the $CaSO_4$:Dy TL material obtained from calibrations by means of a series of controlled heavy-ion irradiations at ground-based particle accelerators measured by Benton and the LET spectra measured in CR-39 passive nuclear track detectors in low Earth orbit, the degree to which the TLDs undermeasure the dose due to their decreased efficiency in registering high-LET radiation is not more than 10%, if no corrections are carried out (Apáthy et al., 2003).

The Pille TL Reader is designed for spacecraft: it is a small, lightweight device with low energy consumption. The reader is capable of heating the dosimeters, measuring the emitted light during the read-out, performing preliminary data evaluation, storing and displaying the results. The measurement results are stored on a removable flash memory card which can store up to 8000 data blocks consisting of the TL glow curve, the time of the last read-out, the results of the background and sensitivity measurement (performed at the beginning of each read-out) and all derived data such as the absorbed dose. Data are not corrected for the loss of dose registration efficiency at higher LET on board; these corrections can be done later on ground, if needed. The main specifications of the Pille TLD system are summarized in Table 2.

4. Cross calibration of the Pille dosimeters

In 2009 four new Pille dosimeters were transported to the ISS. The new dosimeters offered an opportunity to check the measuring sensitivity of the 10 original dosimeters on board. Three of the new dosimeters (A0312, A0313 and A0314) were exposed to 10 mGy $\pm$ 2% dose with a ^{137}Cs gamma source on ground before launch. The fourth one (A0311) was to measure the transport and launch dose. Once they arrived on the ISS, the new dosimeters were evaluated with the on-board Pille reader. The results of these read-outs are presented in Table 3.

The expected dose measured by the three irradiated dosimeters assuming 2% fading for two months, and considering the transport dose and the launch dose measured by dosimeter A0311 with an