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Depth dose distribution measurement on the Foton-M2 bio-satellite by TLD technique

I. Fehér, J.K. Pálfalvi *

HAS KFKI-Atomic Energy Research Institute, P.O. Box 49, H-1525 Budapest, Hungary

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Abstract

In the framework of "Biology and Physics in Space" project of the European Space Agency (ESA), a returning satellite, Foton-M2, carried an open-to-space sample holder outside of the satellite body, called as BIOPAN-5, loaded with exo-biological experiments and dosemeters for *RA*diation *DO*simetry (RADO). One of the RADO experiments (Teflon – TLD) was dedicated to dose distribution measurements of the cosmic radiation by thermo-luminescent (TL) technique. It was found that the maximum surface absorbed dose rate, averaged over the first ~8 mg/cm^2 thickness, was ~2 Gy/d and showed a location dependence due the shading effect of the satellite construction elements. The dose rate decreased nearly by 3 orders of magnitude below 500 mg/cm^2.

Keywords: Foton-M2; Biopan; Space dosimetry; TL dosimetry

1. Introduction

The Biopan experiments were started as early as 1992, summarised by Demets et al. (2005) and presented Table 1. The flight parameters are highly consistent: the orbital inclination is always close to 63°, the altitude is around 300 km and the flight duration is close to two weeks. This consistency enables the investigators to repeat their experiments as necessary under conditions that are quite similar, apart from the sun cycle events. Additionally solar flares – with increasing levels of radiation – may occasionally occur, however, on none of the five completed Biopan flights such flares have been encountered.

The experiments in Biopan are exposed to galactic cosmic rays and the trapped radiation of the inner radiation belt, where the dominant contribution is delivered during crossings of the SAA (South Atlantic Anomaly). In low shielding configurations the electrons in the range of 0.1–5 MeV are the main contributor to the dose. Some contribution is delivered by the belt protons mainly with energies up to 30 MeV. Although, the high Z and energy (HZE) galactic origin particles are always present and deliver a huge dose locally along their path, their contribution to the traditionally defined absorbed dose is negligible. The same is valid for the high energy belt protons and secondary particles like neutrons.

The ESA payload carried by Foton-M2 satellite (launched from Baikonur, Kazakhstan in 31 May, 2005) covered a scientific program consisting of 39 experiments in fluid physics, biology, material science, meteoritic and exo-biology for which the *RA*diation *Do*simetry (RADO) delivers exposure rates for various depth.The RADO experiments were located both in the bottom and the lid part of the BIOPAN-5 container, which was opened after reaching the orbit and closed after 14.625 days, just before landing. To calculate the daily dose rate only the time when the BIOPAN was open is to be considered, since when the lid of Biopan is closed, more than 4.2 g cm^{-2} of additional shielding mass is placed in front of the experiment packages providing a dose reduction of more than three order of magnitude, whereby the influx of electrons and low-energy protons is completely blocked. The peculiarity of

* Corresponding author.
E-mail addresses: palfalvi@aeki.kfki.hu, joepalfalvi@gmail.com (J.K. Pálfalvi).

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Table 1
Flight parameters of Biopan missions

Mission	Year	Spacecraft	Inclination	Altitude (km)	Flight duration (days)	Exposure time (days)
BIOPAN-0	1992	Foton-8	62.8°	221 × 359	15.6	7.8
BIOPAN-1	1994	Foton-9	62.8°	221 × 364	17.6	14.8
BIOPAN-2	1997	Foton-11	62.8°	218 × 375	13.6	10.9
BIOPAN-3	1999	Foton-12	62.8°	217 × 384	14.6	12.7
BIOPAN-4	2002	Foton-M1	Failed			
BIOPAN-5	2005	Foton-M2	63.0°	262 × 304	1 5.8	14.6

the Photon satellites is that their attitude was not stabilised, it was rotating slowly, ~6 times per hour, facing the Earth and the space equally, which resulted in an isotropic exposure. Only when crossing the South Atlantic Anomaly (SAA) there is a remarkable anisotropy of the fluxes. The two halves of the BIOPAN were exposed to the space radiation differently, since the bottom part was partly under the umbrella of the power supply unit. The dose delivered in depth down to 500 mg/cm^2 teflon was measured by TL detectors, utilising the thin layer method, applied also during the flight of the Cosmos-1451 satellite as described by Szabó et al. (1986). The high LET particles (primary galactic and secondary neutrons) were detected by solid state nuclear track detectors as was reported by Pálfalvi et al. (2007).

2. Methods

TL detectors provide a unique possibility to measure the low LET radiation, their sensitivity decreases above 10 keV/μm, and in such an environment where the contribution of the high LET radiation to the total dose is quite low, in the upper few hundred mg/cm^2 layer, the measured dose can be attributed to the low LET radiation nearly in 100%, within the measuring uncertainties. The essence of the depth dose distribution measuring TL telescope is that the low energy radiation reaches the TL block from the top direction only in a narrow solid angle and from the side directions the low energy radiation is filtered out by the stainless steel cylinder as detailed below.

2.1. Preparation

The selected TL materials were $CaSO_4$:Dy (made in Hungary) and ^{7}LiF (TLD-700, Harshaw). These materials in powder form were mixed with high temperature resistant teflon plastic powder in 1:3 and 1:4 w/w ratio, solidified under high pressure and temperature, which resulted in cylindrical rods 6 mm in diameter. Finally some of the rods were sliced into ~30 μm thick layers (~6.6 mg/cm^2) or cut into smaller pieces. In each slice only few hundreds of TL crystals were distributed in the teflon, which rises the detection threshold against the normal one used for working level personal dosimetry (because the signal per unit dose is smaller). However, they were appropriate to measure the high dose expected in the open space for such a long exposure time. Before assembling a telescopic system from the slices they were thermally annealed at 290 °C for an hour to eliminate the previously collected dose. To keep these fine slices flat during this procedure they were placed between two quartz sheets.

The assemblies of the stacks are shown in Fig. 1. The left stack is composed of $CaSO_4$:Dy – teflon slices separated by pure teflon blocks, the middle stack was built up from ^{7}LiF – teflon slices on the top and a block of ^{7}LiF loaded teflon, which was sliced only after the flight when the detectors returned to the laboratory for evaluation. Each type of stack was placed into the same type of stainless steel cylindrical holder (telescope) as shown on the right of Figs. 1 and in 2. The wall thickness was 4 mm. The stack was built up step by step, at first, on the bottom of the holder, at a depth of 2.5 g/cm^2, either a ^{6}LiF or ^{7}LiF detector chip (Harshaw) was placed in a teflon bed to detect the presence of thermal neutrons. Then the TL stack was piled up element by element. It was kept tight by a thin walled stainless still cylinder fixed by a screw, additionally the teflon block was similarly fixed. The cylinder formed an air column of 6 mm above the stack, which was evacuated through a tiny hole when the BIOPAN lid opened. To protect the upper slice against the direct sun exposure a 1.5 mg/cm^2 thick Al foil was applied at the entrance of the telescope. This layer filters out the electrons below ~50 keV energy. The two different stacks were screwed onto a common base plate forming a pair. Two pairs of $CaSO_4$:Dy and ^{7}LiF containing telescopes were placed on the bottom and the lid of the BIOPAN-5 (Fig. 2), a third one was used as control of the transfer dose background from Budapest to Baikonur and back.

2.2. Evaluation

The preparation of the TLD stacks was completed on 2nd May, 2005 in Budapest, the flight ended on 16th June and our detectors were received on 11th July, and the evaluation was performed between 18th and 25th August.

All the TL measurements were performed by a laboratory made, computerised TLD reader. The digitised glow curves were evaluated in such a way that the low temperature peaks were eliminated by the software to decrease the uncertainty due to the short half life of these peaks. This method is very essential for the ^{7}LiF detectors having more low temperature peaks and lower dosimetry peak than the $CaSO_4$.

The low energy (50–1000 keV) electron sensitivity of the $CaSO_4$:Dy material, relative to ^{137}Cs gamma rays, and