APPENDIX O

Depth Distribution of Absorbed Dose on the External Surface of the Cosmos 1887 Biosatellite

by

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DEPTH DISTRIBUTION OF ABSORBED DOSE ON THE EXTERNAL SURFACE OF COSMOS 1887 BIOSATELLITE

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Abstract—Significant absorbed dose levels exceeding 1.0 Gy day^{-1} have been measured on the external surface of the Cosmos 1887 biosatellite as functions of depth in stacks of thin thermoluminescent detectors (TLDs) of U.S.S.R. and U.S.A. manufacture. The dose was found to decrease rapidly with increasing absorber thickness, thereby indicating the presence of intensive fluxes of low-energy particles. Comparison between the U.S.S.R. and U.S.A. results and calculations based on the Vette Model environment are in satisfactory agreement. The major contribution to the dose under thin shielding thickness is shown to be from electrons. The fraction of the dose due to protons and heavier charged particles increases with shielding thickness.

INTRODUCTION

THE DEPTH distribution of absorbed dose in matter is an important characteristic of the radiation environment. It is of particular interest to examine the absorbed dose values which apply to the surface layers of materials placed outside spacecraft.

Experiments measuring absorbed doses under very thin shielding have been made on board the Soviet recoverable satellites since the late seventies using integral-type solid-state detectors. In the Cosmos 936 (1977) and 1129 (1979) biosatellite experiments, thermoluminescence detectors (TLD) of 1.0 g cm^{-2} thickness covered by 0.001–1.0 g cm^{-2} thick opaque materials were mounted on the external surfaces of the satellites (Akatov *et al.*, 1981; Benton, 1983). These experiments have shown that absorbed doses measured outside the satellites are as much as 50–1000 times higher than the absorbed doses measured with similar detectors inside the satellites. The doses increase rapidly with decreasing shielding, thereby indicating that the dominant contribution to the surface dose is from the low-energy component of ionizing radiation.

The measurements were continued on board Cosmos 1514 biosatellite (1983) and other recoverable satellites (1984–1986) using thinner (up to 20 μm) TLDs (Akatov *et al.*, 1985, 1988; Szabo *et al.*, 1986, 1987). In these measurements, the absorbed dose in 0.005–0.03 g cm^{-2} thick detectors covered with 0.001–0.002 g cm^{-2} thick foils was found to be 2–10 Gy day^{-1}. The doses varied as a function of the exposure conditions, namely, orbital parameters, solar activity and shielding by satellite structures. However, the character of the depth distribution of doses remained the same, with the dose decreasing rapidly in the 0.005–0.1 g cm^{-2} thickness interval, then decreasing more slowly.
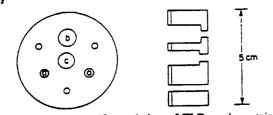
This paper presents the results of the K-6-25 joint Soviet–American dosimetric experiment on board the Cosmos 1887 biosatellite, as well as the results of theoretical calculations for the Cosmos 1887 orbit (altitude of 406 km apogee and 224 km perigee; inclination of 62.8°). The flight lasted from 29 September to 12 October 1987.

EXPERIMENTAL TECHNIQUES

The American ^{7}LiF detectors (Harshaw TLD-700) of two thicknesses (0.00914 and 0.0889 cm) and the Soviet-manufactured 0.8 cm diameter thermoluminescent glass detector of 0.012 and 0.1 cm thicknesses were used in the experiments. The detectors were stacked in vertical cylindrical channels of a metallic container. Two four-channel containers were used in which the ^{7}LiF detectors were stacked in three channels, and the glass detector in one channel. The containers had a diameter of 5 cm and a height of 2 cm (see Fig. 1). The maximum depths of the detector stacks were 3.4 g cm^{-2} for ^{7}LiF and 3.8 g cm^{-2} for glass. The container surfaces facing free space were covered with a Kapton film 0.002 g cm^{-2} thick, metallized on both sides to protect the detectors against direct sunlight and against

FIG. 1. Drawing, half actual size, of TLD stack container (Al) for Cosmos 1887 experiment. The U.S. detectors of $0.32\,\text{cm} \times 0.32\,\text{cm}$ were in hole (a), U.S. detectors of $0.64\,\text{cm} \times 0.64\,\text{cm}$ were in hole (b) and Soviet detectors of 0.8 cm diameter were in hole (c).

heating. The optical density of the metallized film surfaces is 3.

The detector containers were mounted in a special device covered with a lid for protection during re-entry. The device with the lid open was fastened under a fairing on the external surface of the satellite before launch. (When in orbit, the fairing is jettisoned; on re-entry, the lid is closed. In this manner the detectors are open to nearly free space while in orbit, and are heat-shielded during the satellite launching and recovery periods.)

After the flight, the detectors were processed at the laboratories in the U.S.S.R. and the U.S.A. by similar methods. The ^{7}LiF detectors were measured using the HARSHAW Model 4000 TLD Reader, and the glass detectors using the NHZ-203 instrument. The detectors were calibrated separately in the U.S.S.R. and the U.S.A. using ^{137}Cs γ-rays.

RESULTS AND DISCUSSION

In Fig. 2 are shown the measured and calculated values of absorbed dose as a function of shielding thickness for the Cosmos 1887 experiment. The dose levels in the least protected upper detectors ($\sim 0.002\,\text{g cm}^{-2}$) were 1.2–2.5 Gy day^{-1} and decreased by a factor of $\sim 10^3$ at a 1 g cm^{-2} depth. This confirms the earlier observations indicating the occurrence of substantial low-energy particle fluxes in free space.

The character of the depth distribution of the dose inferred from the American- and Soviet-made detectors has proved to be the same despite some differences in the absolute dose values. The main difference is observed in the uppermost detectors where the dose in the American detectors is about twice as high as the Soviet detector dose. This may be due to the difference in the detector thickness (0.024 g cm^{-2} for ^{7}LiF (U.S.A.) and 0.31 g cm^{-2} for TL glass (U.S.S.R.), since the averaged specific value of dose in a thicker detector will be lower if the dose falls significantly across the thickness of the detector. At greater depths, the discrepancy in the readings decreases and is in the range of 20–40%. Some of the variations may arise from differences in detector arrangement; for instance, the American detectors were not packed closely in the cylindrical assembly
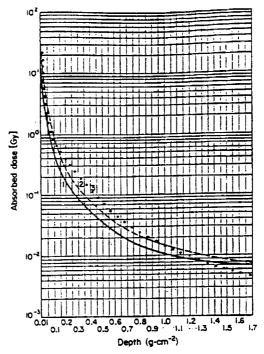

FIG. 2. Depth distribution of absorbed tissue dose on the external surface of Cosmos 1887 biosatellite. The dose measurement error is ~10%. Curve 1: data of the Soviet-made glass TLD. Curve 2: data of the American-made ^{7}LiF TLD. Curve 3: calculated data.

channels. Also, there may be small differences in detector-calibration procedures.

The depth distributions of doses were calculated considering the contribution from trapped electrons and protons and galactic cosmic rays (GCR). The flight occurred near solar minimum so no solar flare proton contribution was considered. Trapped radiation belt fluxes were calculated using the Vette AE8-MIN electron and AP8-MIN proton model environments (Teague *et al.*, 1976; Sawyer and Vette, 1976). According to this data, most of the electron flux lies within a 0.05–4.5 MeV energy range, while the proton flux covers a 0.1–450 MeV range. The dose at small shielding thicknesses is due to the proton and electron ionizing energy loss, whereas the electron bremsstrahlung makes a significant contribution to the dose for thicknesses in the range above 2 g cm^{-2}.

The methods used to calculate the GCR spectra and, hence, the doses in low Earth orbit are the same as described in Dudkin *et al.* (1986). The calculations allowed for the deformation of the GCR particle spectrum in the Earth's magnetic field and for the secondary radiation generated in inelastic interactions of particles in the shielding. The absorbed doses from both the trapped and the GCR particles were calculated for the case of isotropic incidence of a broad particle beam onto an Al planar shield and for solar minimum conditions.

The calculation results have shown that the doses under low shield thicknesses (<1 g cm^{-2}) are due

Table 1. Component composition of cosmic ray dose (%) under various shield thicknesses on Cosmos 1887

Shield thickness (g cm^{-2}) Particle species	0.1	0.5	1.0	1.5	2.0	5.0
e	99.2	95.6	79	42.8	13.7	2.2
p	0.6	2.7	11.8	30	42.5	34.0
GCR	0.2	1.7	9.2	27.2	43.8	63.8

mainly to ionization loss of radiation belt electrons. The fraction of dose due to radiation belt and GCR protons and to electron bremsstahlung increases with shield thickness. Comparisons between the calculated and experimental data shown in Fig. 2 indicate that they are in good agreement. The calculated data used to analyze the doses from the different radiation types outside the biosatellite are presented in Table 1.

As noted in Szabo et al. (1987), the average dose rate outside satellites depends substantially on orbital parameters. The character of the dependence of the dose on shielding thickness varies also and is very difficult to describe with a unified expression applying to different spacecraft orbits. We are of the opinion that further studies should be aimed at examining the depth distribution of the absorbed dose for different orbital parameters and different solar activity periods. In so doing, particular attention should be paid to the experimental geometry and to careful calibration of detectors, especially in the interval of high doses of about 10–1000 Gy where linearity of the dose characteristics is observed to vary in some types of detectors.

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