

## A NEW METHOD FOR DETERMINING THE EQUIVALENT DOSE OF ASTRONAUTS

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### Abstract

One of the many risks of long-duration space flights is the excessive exposure to cosmic radiation, which has great importance particularly during solar flares and higher solar activity. Since space radiation mainly consists of charged heavy particles, the equivalent dose differs significantly from the absorbed dose. The objectives of this project are to develop and manufacture a three-axis silicon detector telescope, and to develop software for data evaluation of the measured energy deposition spectra. Research and development began in the KFKI Atomic Energy Research Institute several years ago. Elements of the 3D telescope system, issues of the electronic block diagram, requirements for the mechanical construction and possibilities of data handling and data evaluation are analyzed in this paper.

**Keywords:** *radiation, dosimetry, equivalent dose, LET telescope*

## 1 Introduction

The radiation field in space is a mixture of different particles differing in energy and varies considerably with time. Concerning the origin of the radiation two

components can be distinguished. One is the galactic component mostly consisting of energetic charged particles (protons, alpha particles, heavier ions and electrons in the energy range of 1 MeV –  $10^{14}$  MeV) coming from the outside of the Solar System, the flux of which is almost constant and isotropic (Simonsen et al., 2000).

The other component is the solar cosmic radiation consisting of charged particles having a softer (eV - GeV) energy spectrum and most of the time a very low intensity. However, in case of solar flares its intensity can be orders of magnitude higher than that of the galactic component.

On orbits around the Earth the radiation environment is even more complicated. Due to the interaction between the magnetic field of the Earth and the solar wind the originally dipole field is distorted and toroidal radiation belts are formed by the trapping of charged particles (in particular electrons and protons).

In Low Earth Orbit (LEO) the astronauts suffer twice as much equivalent dose when passing the South Atlantic region as along other regions of the orbit. This phenomenon is called the South Atlantic Anomaly (SAA) and caused by an offset and tilt of the magnetic axis with respect to the Earth's axis of rotation. Due to that asymmetry the lower radiation belt protrudes into LEO and therefore the radiation field is mainly determined by the trapped particles within this region (Kivelson, 1995).

## 2 Dosimetry terminology

In order to describe the effects of radiation on humans various terms have been defined. The absorbed dose  $D$  describes the amount of energy ( $dE$ ) absorbed in mass  $dm$ :

$$D = dE/dm$$

Since the stochastic biological effect of particles of different type and energy are different, the term of equivalent dose was introduced in the recommendation of the ICRP (International Commission on Radiological Protection), which takes into account the ionisation density as well:

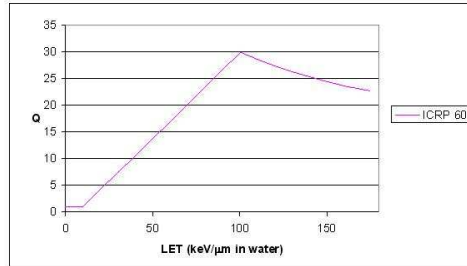
$$H_{T,R} = \sum_R D_{T,R} \cdot w_R,$$

where  $H_{T,R}$  is the equivalent dose,  $D_{T,R}$  is the absorbed dose in tissue  $T$  and  $w_R$  is the radiation weighting factor of radiation  $R$ . The values of  $w_R$  are broadly

compatible with the values of  $Q$ , which are related (Fig. 1) to the Linear Energy Transfer (LET):

$$LET = dE/dx,$$

where  $dE$  is the average energy locally imparted to the material by an incoming charged particle of a specified energy over a  $dx$  path length (ICRP 60, 1990).



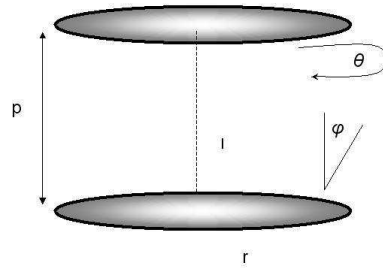
**Figure 1:** The quality factor as a function of the LET (ICRP 60, 1990)

### 3 Instrumentation

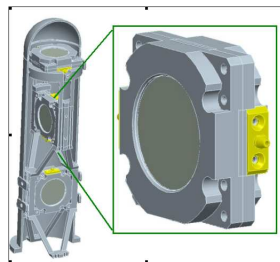
Since space radiation mainly consists of charged heavy particles the equivalent dose differs significantly from the absorbed dose. In order to determine the average  $w_R$  of these particles the development of a three-axis silicon detector telescope, called Tritel began in the KFKI Atomic Energy Research Institute several years ago. The main benefit of the three-axis arrangement is that it is going to exclude mostly the highly anisotropic sensitivity of the recently used one-dimensional silicon telescopes.

The geometric parameters (Fig. 2) of the 3D silicon LET telescope were defined, results of previous measurements were used as a benchmark. Features of various types and sizes of telescopes were analyzed (Pázmándi, 2004).

Tritel (Fig. 3) is based on six identical passivated implanted planar silicon detectors having a thickness of  $300 \mu\text{m}$  and a sensitive area of  $450 \text{ mm}^2$ . The detector chips of each axis are mounted at a distance of 12 mm, which means an opening angle of  $120^\circ$ , and connected as AND gate in coincidence. The instrument cannot provide the primary energy spectrum only the energy deposit of charged particles coming from a certain solid angle. Thus the absorbed dose, LET spectrum,  $w_R$  and equivalent dose can be determined for different regions of the orbit (Pázmándi, 2004).



**Figure 2:** The main geometric parameters of the telescope ( $r$  is the radius of the detector and  $p$  is the distance between the detector chips) (Pázmándi, 2004)



**Figure 3:** The arrangement of the telescopes ( $x$ ,  $y$  and  $z$  axis) in the external unit

Fig. 4 shows the simplified block diagram of Tritel: Each detector of the 3D silicon LET telescope is connected to a charge sensitive preamplifier. After initial amplification and pulse shaping the pulses are amplified and connected to a coincidence circuit in each axis. The pulses of the measuring detector and the signal of the coincidence circuit (the last as a flag) are then fed to a peak detector. The analogue outputs of each peak detectors are sent to a flash amplitude analyser. The address of the channel together with the coincidence flags are sent to a digital multiplexer.

The energy spectrum can be used to obtain the LET spectrum because of the pathlength limitation due to the telescope geometry. The evaluation software will convert the LET spectrum to an average  $w_R$ . The final output of the system - including ground evaluation as well - will be the equivalent dose on board International Space Station (ISS).

Since the radiation environment in the SAA differs so much from that of the rest of the orbit it is worth considering the two segments separately. The

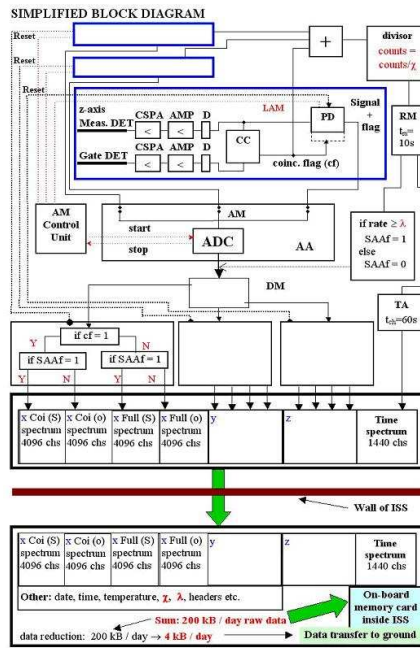


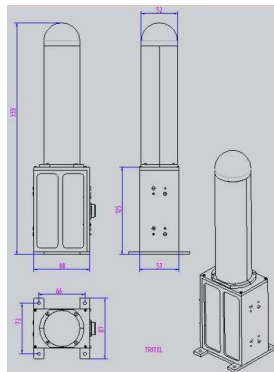
Figure 4: Simplified block diagram of Tritel three-axis silicon detector telescope

two regions differ not only in the LET spectrum of the particles but in intensity as well, which makes differentiation between them possible on the basis of measuring count rates in the detectors. The rate of the signals coming from the coincidence circuits (CC) of the three axes is measured with a ratemeter (RM). From the consecutive 10-second-long measurements a time analyser (TA) will produce a time spectrum from which the rate at the boundary of the SAA ( $\lambda$ ) can be determined.

Every 24 hours the multi-channel analyzer provides altogether 12 different primary spectra (for each axis two gated and two full spectra, one taken in the South Atlantic Anomaly and the other in the rest of the orbit).

## 4 The Mechanical Construction

The Tritel 3D telescope system onboard ISS will consist of two units: an external unit (Fig. 5), which comprises the three silicon detector telescopes and the signal processing units and a unit located inside ISS where all the onboard digital data processing take place.



**Figure 5:** *Technical drawings of the external unit of Tritel*

The external unit will be attached to the zenith side of ISS by means of a 30-centimeter-long boom. In this way the axis of the unit can be adjusted to the zenith and the degree of hiding by the other instruments located on the platform can be reduced, as well.

Data of the measurements are stored in the memory of the internal unit and can be saved to a memory stick. A menu-driven graphical interface will help the astronauts to change the settings, download data or update the software. Crew change onboard the ISS takes place once every six month, hence the memory stick may be returned to Earth only at that time. Another possibility of data transfer is the data transmission to ground by using the data transfer system of the space station. This solution is independent of ISS crew change but it has an important drawback: due to the limitations of data transmission only a limited amount of data can be transferred to ground therefore the measurement data must be reduced to some extent.

**Table 1:** The reverse current of the detector in original and telescope mounting (the measured data and data calculated from datasheet values)

Detector mounting	spec.(20°)		T [°C]	measured $I_{rev}$ [nA]	calculated $I_{rev}$ [nA]
	U [V]	$U_{max}$ [V]			
original:	70	90	25±1	67±1	72±10
telescope:			23±1	56±1	55±8

## 5 Measurements

Testing of the detectors and the analog circuits has already begun. The reverse current measurements have shown that the Canberra FD450-24-300RM detectors are suitable for Tritel telescopes because of their relatively low and constant reverse current in the operating point of the device ( $U = 70V$ ). After mounting the detector chip in the prototype of the telescope, its parameters were checked (Fig. 6).

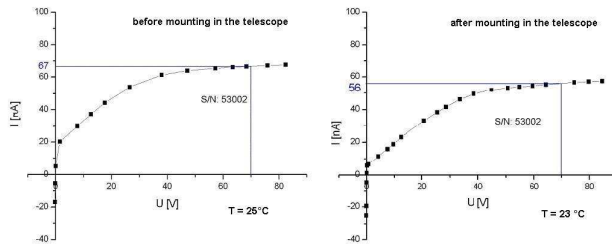
**Figure 6:** The reverse current of Canberra silicon detector as a function of the bias

Table 1 shows the reverse current measured in the operating point of the detector before and after mounting in the telescope. The values were also calculated from the data given in the datasheets of the detector. From the results it can be noticed that the difference in the reverse current can be attributed to the temperature difference of the two measurements.

The construction of the first model of the analog signal processing chain (preamplifier - shaping circuit - amplifiers) has been finished as well. The final optimization of the parameters of the system - among others the improvement

of the signal-to-noise ration - is under way.

## 6 The future of Tritel

In the near future the Institute of Biomedical Problems (IBMP), Moscow is going to provide us the opportunity to carry out measurements on the Russian platform of the International Space Station.

Within the framework of the Student Space Exploration and Technology Initiative (SSETI) created by the ESA Education Department, a more compact version of Tritel (Tritel-S) will be operated onboard the European Student Earth Orbiter (ESEO) in Geostacionary Transfer Orbit. The device may be a precursor of a subsequent version of Tritel planned for a future Mars probe, too.

## 7 Conclusions

The elements of the Tritel device together with the mechanical and electrical requirements for the mechanical construction and the possibilities of data handling and data evaluation were analyzed. The construction of the telescope prototype and the first model of the analog signal processing chain has been finished. Further optimization of the parameters and the calibration of the system are under way.

The 3D silicon detector telescope would provide the environmental information for the absorbed dose, LET spectrum,  $w_R$  and equivalent dose as well and should be the first such device used for measuring the dose astronauts are subjected to.

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