Tritel: 3D Silicon Detector Telescope used for Space Dosimetry

*Tamás Pázmándi, Attila Hirn, Sándor Deme , István Apáthy, Antal Csőke, *László Bodnár*

KFKI Atomic Energy Research Institute,
H-1525 Budapest, P.O. Box 49, Hungary
pazmandi@sunserv.kfki.hu

**BL-Electronics*
H-2083 Solymár, Sport 5, Hungary

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.

Radiation weighting factor, which is a function of the linear energy transfer of the radiation, is used to convert absorbed dose to equivalent dose. 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 (Tritel), and to develop software for data evaluation of the measured energy deposition spectra. The 3D silicon telescope should be the first such device used for measuring the dose astronauts are subjected to.

Research and development began in the KFKI Atomic Energy Research Institute several years ago. The geometric parameters 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.

Elements of the Tritel 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. First results of the calibrations are presented as well.

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 (GCR, Galactic Cosmic Radiation) 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. On Earth's orbit around the Sun its value is about 10^6 particles/(week*cm^2) which yields an average doserate of 2.5 mGy/week [4].*

The other component is the solar cosmic radiation consisting of charged particle having a softer (eV – GeV) energy spectrum than that of the galactic particles. Most of the time its intensity is very low but in case of solar flers 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 torodial radiation belts are formed by the trapping of charged particles (in particular electrons and protons) by the Earth's magnetic field. The magnetic shielding has a maximum above the Equator and it is decreasing towards the poles.

In Low earth Orbit (LEO) the astronauts suffer twice as much equivalent dose when passing the South Atlantic region as in 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 [2].

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 energy (dE) absorbed in mass dm:

$$D = \frac{dE}{dm}. \tag{1}$$

Since the stochastic biological effect of particles of different type and energy are different, the term of equivalent dose (2) was introduced in the recommendation [1] of the ICRP (International Commission on Radiological Protection), which takes into account the ionisation density as well:

$$H_{T,R} = \sum_R D_{T,R} \cdot w_R, \tag{2}$$

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 to the Linear Energy Transfer (LET) [1]:

$$LET = \frac{dE}{dx}, \tag{3}$$

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.

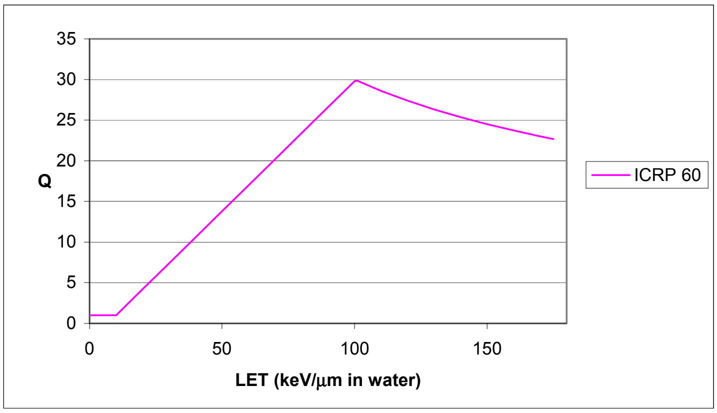

Figure 1: The quality factor as a function of the LET [1]

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 radiation weigthing factor 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 (

Figure 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 [3].

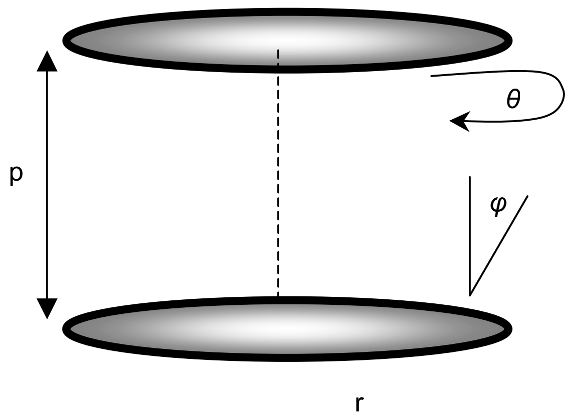

Figure 2: The main geometric parameters of the telescope (r is the radius of the detector and p is the distance between the detector chips) [3]

The three dimensional silicon telescope Tritel is based on six identical PIPS detectors having a thickness of 300 μm and a sensitive area of 450 mm^2 and designed to measure the energy deposit of charged particles. The detector chips of each axis are mounted at a distance of 12 mm which means an opening angle of 120° and connected as AND gate in coincidence. The instrument cannot provide the primary energy spectrum only the energy *deposit of charged particles (protons, alpha particles and heavier ions) coming from a certain solid angle. Thus the absorbed dose, LET spectrum, radiation weighting factor and equivalent dose can be determined for different regions of the orbit [3].*

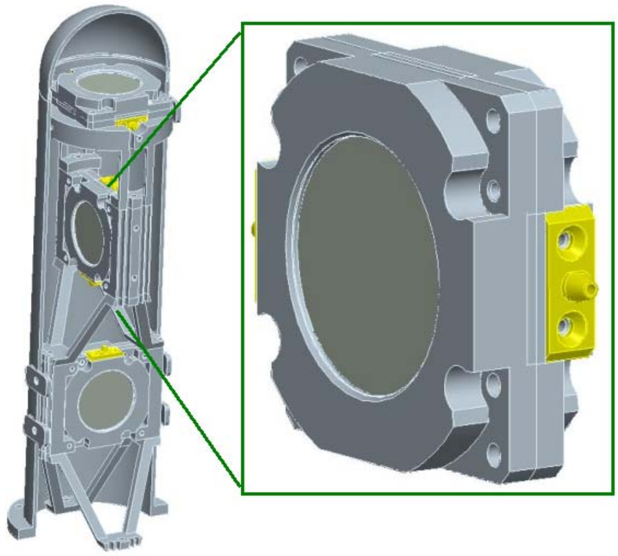

Figure 3: The arrangement of the three telescopes (x, y and z axis) in the external unit

Figure 4 shows the simplified block diagram of Tritel: Each detector of the three-axis 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.

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 two regions differ not only in the LET spectrum of the particles but in intensity, as well which makes differentiation between them on the basis of measuring count rates in the detectors possible. 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 (λ) can be determined.

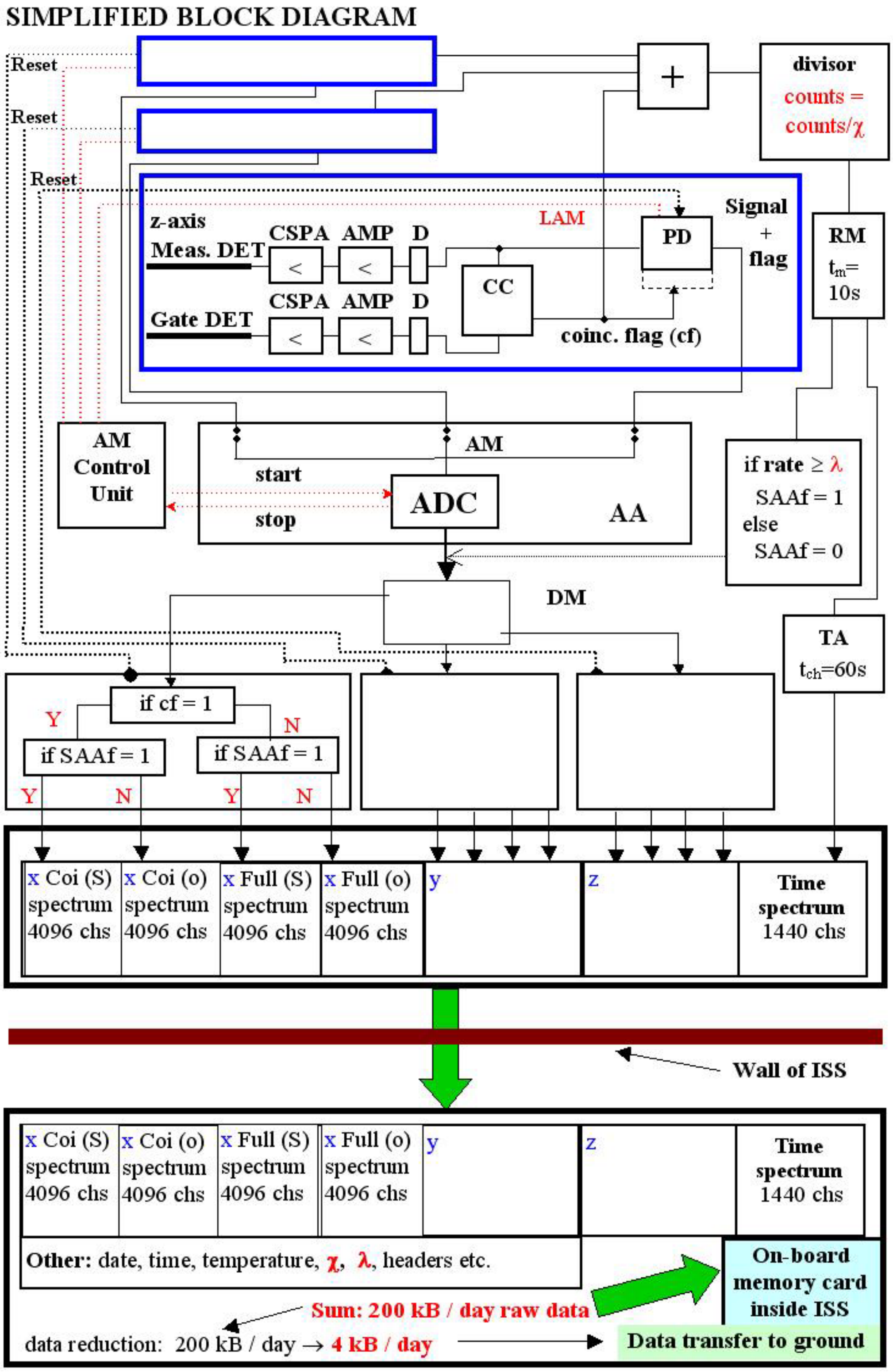

Figure 4: Simplified block diagram of Tritel three-dimensional silicon detector telescope

Every 24 hours the multi-channel analyzer provides 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 the International Space Station (ISS) consists of two units: an external – or detector – unit (Figure 5), which comprises the three silicon detector telescopes and the signal processing units and a unit located inside ISS (internal unit) where all the onboard digital data processing take place.

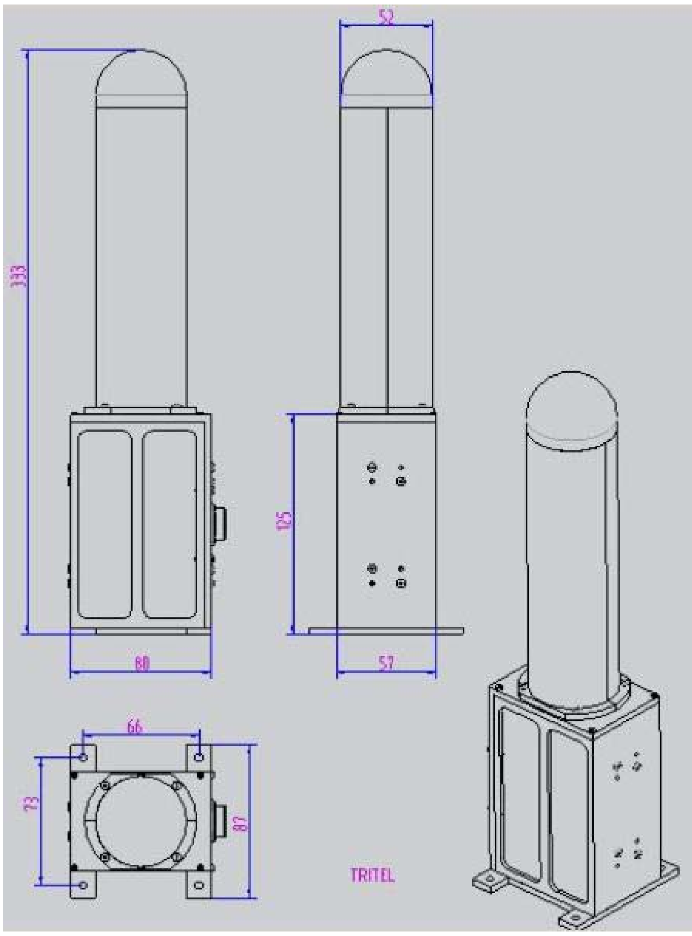

Figure 5: Technical drawings of the External Unit of Tritel

The external unit will be attached to the zenith side of the 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 at the same time.

Data of the measurements are stored in the memory of the internal unit of Tritel 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 the 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.*

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 (Figure 6).

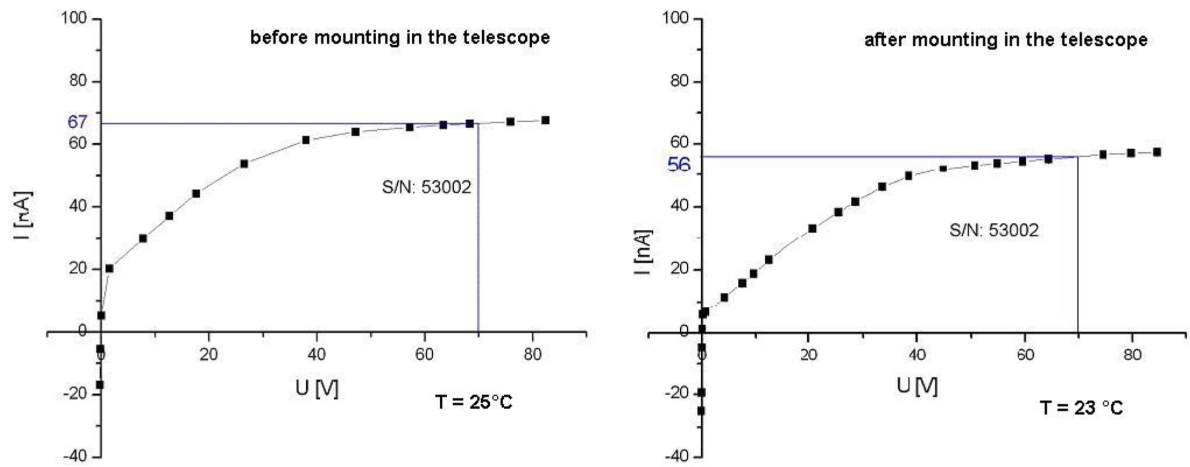

Figure 6: The reverse current of the Canberra fully depleted silicon detector as a function of the bias

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 form 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.

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

Detector (S/N: 53002) mounting	Specification (datasheets)			T [°C]	Measured	Calculated
	U [V]	U_{max} [V]	$I_{reverse}$ (20°C) [nA]		$I_{reverse}$ [nA]	$I_{reverse}$ [nA]
original:	70	90	36	(25 ± 1)	67 ± 1	72 ± 10
telescope:				(23 ± 1)	56 ± 1	55 ± 8

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 in order to actively involve European students in real space missions, 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 with the possibilities of data handling and data evaluation were analyzed. The construction of the telescope prototype and of 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, radiation weighting factor and equivalent dose as well and should be the first such device used for measuring the dose the astronauts are subjected to.

REFERENCES

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[4] Simonsen, L. C., Wilson, J. W., Kim, M. H., Cucinotta, F. A.: Radiation exposure for human Mars exploration, Health Phys. 79(5):515-525, 2000