COCORAD AND TECHDOSE COSMIC RADIATION EXPERIMENTS ON BOARD BEXUS STRATOSPHERIC RESEARCH BALLOONS

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ABSTRACT

Due to significant spatial and temporal changes in the cosmic radiation field, radiation measurements with advanced dosimetric instruments on board spacecrafts, aircrafts and balloons are very important. The main scientific goal of our experiments was to measure the effects of the cosmic radiation mainly from dosimetric point of view at lower altitudes where measurements with orbiting spacecrafts are not possible. The main technical goal was to develop a balloon technology platform for advanced cosmic radiation and dosimetric measurements.

1. INTRODUCTION

Among many other student projects ESA Education Office announces a call for proposals annually for the REXUS/BEXUS (Rocket and Ballon Experiments for University Students) flights for university students. The REXUS/BEXUS programme allows students from universities and higher education colleges across Europe to carry out scientific and technological experiments on research rockets and balloons. Each year two balloons capable of lifting their payloads to a maximum altitude of 35 km, depending on total experiment mass (40-100 kg) are launched 145 km North of the Arctic Circle from Sweden, carrying experiments designed and built by student teams [1].

The COCORAD and TECHDOSE Hungarian student experiments were selected to take part in the BEXUS-12 and BEXUS-14 projects. The experiments flew on board the BEXUS-12 and BEXUS-14 stratospheric balloons on the 27th of September 2011 and on the 24th of September 2012 from ESRANGE Space Center. The experiments used the TRITEL three dimensional silicon detector telescope and in case of the TECHDOSE experiment additional Geiger-Müller counters (GM) for active monitoring. Several thermoluminescent dosimeters (Pille system) were used in order to measure the excess absorbed dose of the flight and compare with the active results, and in case of the TECHDOSE experiment Solid State Nuclear Track Detectors (SSNTDs) to measure the contribution of the thermal neutrons. The main technological and scientifical supporter of the experiments was the MTA Centre for Energy Research (the former KFKI Atomic Energy Research Institute). The present paper addresses the main overview of the two experiments and some preliminary results are also shown.

2. THE MAIN GOALS OF THE RESEARCH STUDIES

Commercial airplanes are flying at higher and higher altitudes and the frequency of manned space flights is increasing faster nowadays than before. These facts justify the importance of cosmic radiation and dosimetric measurements with advanced instruments and techniques. Several measurements have been performed on the cosmic radiation field from the surface of the Earth up to the maximum altitudes of research airplanes (the lower limit of the stratosphere). However the cosmic radiation field is not well known between 15 km and 30 km. The incoming primary cosmic radiation interacts with the Earth's magnetosphere and the atmosphere [2] providing a complex radiation environment (see Fig.1).

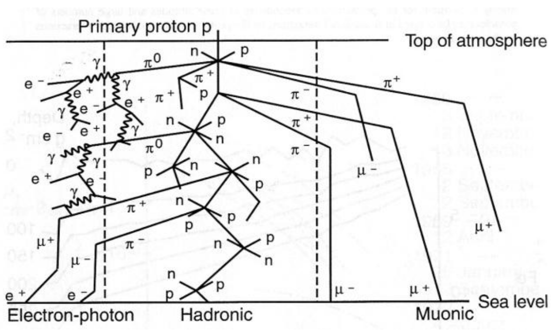

Figure 1. Schematic representation of the secondary particle production in the atmosphere [3], [4].

The main technical goal of our experiment was to develop a balloon technology platform for advanced cosmic radiation and dosimetric measurements to fulfil the scientific goals of our research studies which are the follows:

- to give an almost complete assessment of the cosmic radiation field at the altitude of the stratospheric research balloons;
- to measure the charged particles (in a wide LET range; LET – Linear Energy Transfer, means average energy locally imparted to the material by an incoming charged particle of a specified energy over a *dx* path length) and their dose contribution at the altitude of the stratospheric research balloons;

- to measure the contribution of thermal neutrons using Solid State Nuclear Track Detectors (SSNTDs) at the altitude of the stratospheric research balloons;
- to study the effects of the atmosphere, the Earth's magnetic field and the solar activity on the cosmic radiation field in the stratosphere.

3. INSTRUMENTATION

The experiments used two different types of measurement system during the flight of the BEXUS balloons. One of them was an active space dosimetry system, the TRITEL three-dimensional silicon detector telescope with additional Geiger-Müller counters and the other one was the passive monitoring system. The passive system included Pille thermoluminescent (TL) dosimeters and SSNTDs. In the following sections a short overview of these instruments is given.

3.1 TRITEL telescope

TRITEL is a three dimensional silicon detector telescope comprising six identical fully depleted, passivated implanted planar silicon (PIPS) detectors and designed to measure the energy deposit of charged particles. The detectors are connected as AND gate in coincidence in pairs forming the three orthogonal axes of the instrument (Fig. 2).

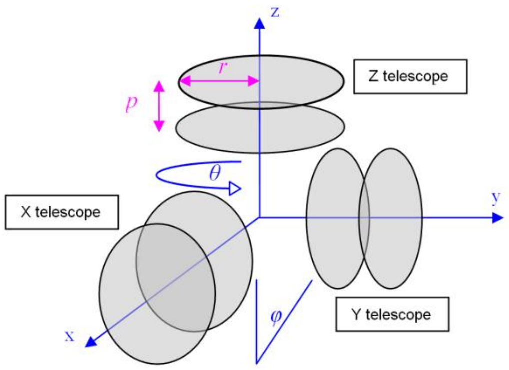

Figure 2. 3D telescope geometry (r is the radius of the detectors, p is the distance between two detectors in the telescope) [5].

By evaluating the deposited energy spectra recorded by TRITEL the absorbed dose, the energy deposition spectra in three directions, the quality factor and the dose equivalent can be determined. Since we are interested in the equivalent dose in tissue, the energy deposition spectra in silicon are converted to LET spectra in human tissue.
Although the instrument can't determine the arrival direction of the individual particles, due to the three-axis arrangement an assessment of the angular asymmetry of the radiation might be possible. Another, even more important advantage of the geometry is that TRITEL has an almost uniform sensitivity in 4π. The effective surface of each detector is 220 mm^2 with a nominal thickness of 300 μm.

3.2 Pille TL space dosimetry system

The development of the Pille thermoluminescent dosimeter system began in the 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. The Pille TL dosimeter contains $CaSO_4$:Dy TL material produced by the Budapest University of Technology and Economics. 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 holds 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.
The Pille TL Reader (Fig. 3) is designed for spacecraft: it is a small, light-weight 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 in the beginning of each read-out) and all derived data such as the absorbed dose [6].
One of the main advantages of the Pille TL system is the possibility of the onsite data acquisition and evaluation, which means no transport dose in the calculations.

Figure 3. The Pille TL dosimeter system in its transporting case (reader and ten dosimeters).

3.3 SSNTDs

Taking into account that in balloon experiments it is difficult to use heavy instrumentation and devices that require bulky power supply or batteries, the Hungarian researchers elaborated a method to apply light weight and passive SSNTDs.

The SSNTD detects charged particles coming from the environment or generated inside its own material by nuclear reactions. The principle of charged particle registration seems to be quite simple: a particle entering the detector material produces radiation damage (latent track) along its path by breaking the chemical bonds. In this zone of few tens of nm, the damaged material can be easily dissolved (etched off) by appropriate chemical reagents meanwhile the bulk material removal is much less. The prolonged etching enlarges the latent track up to a measure when it becomes visible by an optical microscope. Usually, the detector material is a special plastic sheet, in our case, it is a thermoset one manufactured from Polyallyl Diglycol Carbonate (PADC), called TASTRAK, by TASL Ltd. (Bristol, UK) [7].

To detect the neutrons first they need to be converted to charged particles such as protons or alpha particles via nuclear reactions. There are few requirements to select the appropriate neutron-to-charged particle converter material: it should be easily available, chemically stable, solid material, having high reaction cross section and the generated charged particle should be well detectable. Two reactions can be considered as summarized in Tab. 1.

Table 1. Thermal neutron reactions producing charged particles detectable by SSNTD [8].

Reaction	Cross section (barn)	Isotopic abundance (%)	1st particle energy (MeV)	2nd particle energy (MeV)
$^{10}B(n,\alpha)^{7}Li$	3571	19.9	E_α=1.47	E_{Li}=0.84
$^{6}Li(n,\alpha)^{3}H$	941	7.5	E_α=2.05	E_H=2.73

The evident selection is the boron if an appropriate compound is available, because of the high cross section and isotopic abundance, as well as, both charged particles are possibly detectable. It means that their range in the detector material and the linear energy transfer (LET) are satisfactory to enlarge the resulting tracks by a cheap chemical reagent as shown in Tab. 2. To observe the developed tracks, the surface removal by etching needs to be less than the particle range in the detector material. From previous works [8] it is known that the surface etching velocity (bulk etch rate) of the 1 mm thick TASTRAK material is 1.34 μm/h if etched in 6 M NaOH at 70°C.

Table 2. Calculated (SRIM2008 [9]) LET and range of particles and the expected resulting particle area after etching in 6 M NaOH at 70°C for 3 and 0.75 hours, respectively.

Particle energy (MeV)	LET (keV/μm)	Range (μm)	Etching time (h)	Track area (μm^2)
E_α=1.47	234	6.1	3	~37.4
E_{Li}=0.84	440	3.2	0.75	~40

The area of the alpha particle tracks is predictable by a computer code, however, no such a code is available for the Li particle. After selecting the boron containing compound preliminary experiments are needed to determine the expected Li track area and prove the validity of the calculated alpha track area, in order to evaluate reliably the detectors exposed on a balloon.

Recently ^{10}B powder and natural boron coated plastic sheets are available for the converter at the Radiation Protection Department of the MTA Centre for Energy Research. Further search is needed to find commercially available boron converter or elaborate a method to manufacture it from the ^{10}B powder.

The detector assembly should contain 2 or 3 sheets of TASTRAK SSNTD in contact to the boron containing converters packed in an appropriate holder presented in Fig. 4.

The thermal neutron detection efficiency is to be studied at the neutron exposure facility of the Centre for Energy Research. In the knowledge of this the unknown thermal neutron flux can be estimated from the track detector measurements.

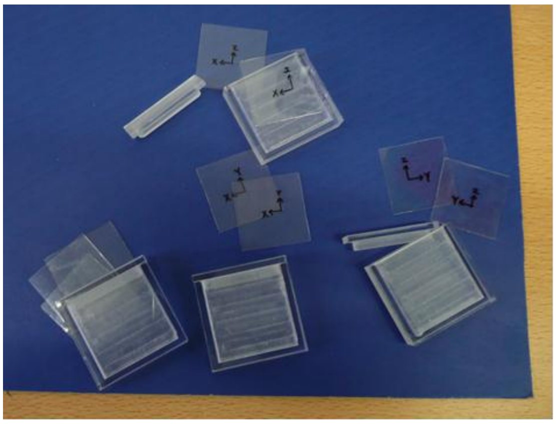

Figure 4. Holders and TASTRAK SSNTDs used in the balloon experiments.

3. EXPERIMENT OVERVIEW

The key elements of the TECHDOSE experiment setup are:

- the TRITEL 3D silicon detector telescope (function: active radiation sensor and data taking unit);
- two Geiger-Müller counters (function: active radiation sensor unit);

- Pille thermoluminescent “bare dosimeters” (function: passive radiation sensors unit);
- Solid State Nuclear Track Detectors (function: passive radiation sensors unit);
- temperature sensors (function: active thermal sensor unit);
- the Experiment Power System (function: provide energy needed for the experiment);
- the E-link interface unit (function: communication with the E-Link system);
- thermal insulation and heaters (function: thermal control).

TRITEL, the Geiger-Müller counters and the temperature sensors are supplied with power by the Experiment Power System. The temperature sensors provide temperature information in given points of the experiment. The Geiger-Müller counters provide the count rate of the incoming charged particles and photons. TRITEL provides deposited energy spectra, time spectra (primary and coincidence too) and housekeeping data. The data of the GM counters and the temperature sensors will be collected in the TRITEL data collecting unit. All the measured data, on the one hand, are stored in the TRITEL internal memory, on the other hand, transferred to the ESRANGE Airborne Data Link (E-link) system. After the experiment is over all the data are downloaded to a personal computer on ground connected to TRITEL. Data are then further processed and evaluated according to the experiment objectives.

Being passive detectors, the TL dosimeters and the Solid State Nuclear Detectors do not require power supply during measurement. The uploaded dosimeters and detectors as well as the reference dosimeters that remain on ground during the mission are read-out before and after the experiment on ground by using a portable reader. The difference of the two doses is the excess dose of the flight. In case of the TL dosimeters dividing the excess dose by the time of flight the average excess dose rate of the flight is obtained. In case of the Solid State Nuclear Track Detectors the thermal neutron contribution can be determined. The experiment setup can be seen in Fig. 7.

3.1 Mechanical design

The mechanical design had to fulfil the design requirements according to the vibration profile of the gondola and the very high accelerations present mainly during landing. The experiment box had to withstand the 8 m/s landing velocity and the design loads +/-10 g in the vertical direction and +/-5 g in the horizontal directions [1].

To fulfil these requirements a mechanical protection box is used as an external box (Experiment Unit). Inside the external box the experiment and its parts can withstand the possible accelerations during the mission. The Experiment Unit contains the electronics of the experiment, an Ethernet converter, as well as the TRITEL and the Pille dosimeters. These parts are mounted together and covered with thermal insulation. Mechanical protection inside the box is provided by spring steel sheets covered by a thin felt layer (see Fig. 5).

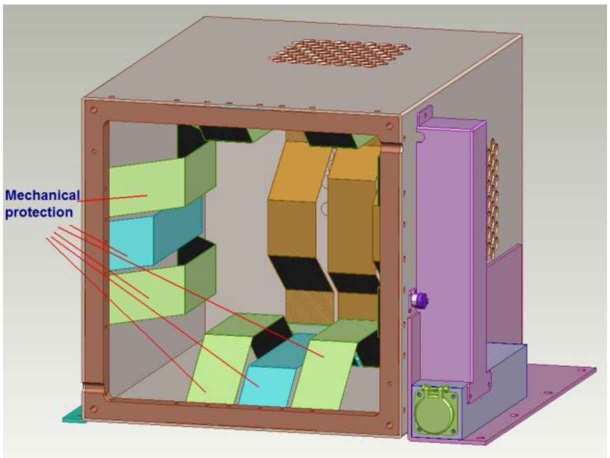

Figure 5. The mechanical protection inside the Experiment Unit.

The mechanical diagrams of the experiment hardware can be seen in Fig. 6.

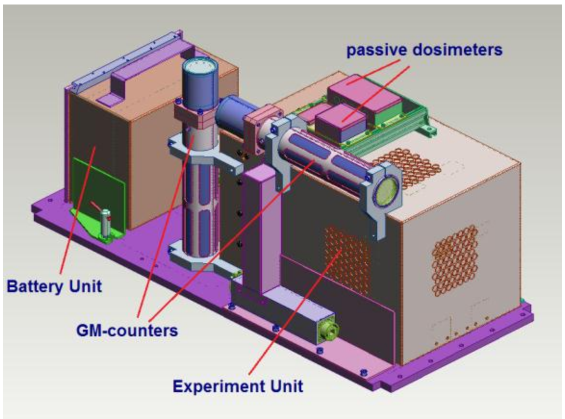

Figure 6. The mechanical design.

The batteries (Battery Unit) are separated from the experiment (Experiment Unit) itself. In this way the Battery Unit is easily removable in case of danger.

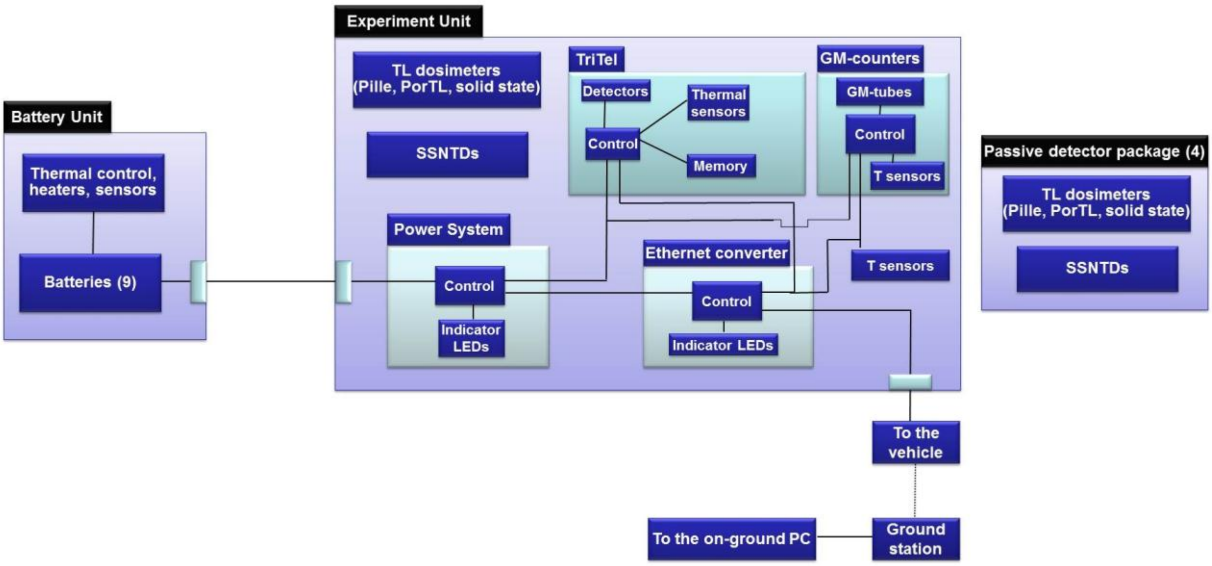

Figure 7. The experiment setup.

3.2 Thermal design

Since the stratosphere is a very harsh environment with very low temperatures it was important to use relevant thermal design to protect the experiments during the flight of the balloon.
The temperature in the stratosphere during a typical BEXUS flight can be as low as -90°C [10]. To protect the sensitive parts of the experiments we used a thermal cover and thermal heaters where it was needed. The thermal cover used in case of the Experiment Unit can be seen in Fig. 8.

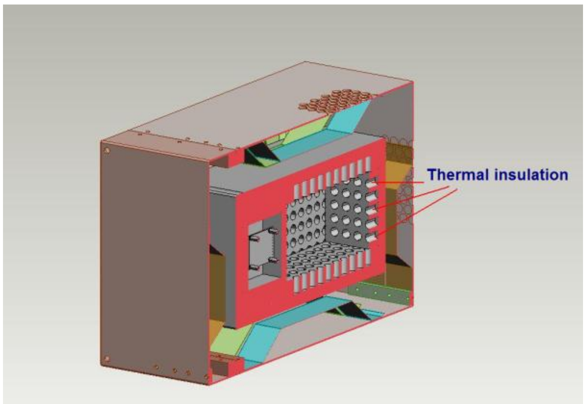

Figure 8. Thermal insulation inside the Experiment Unit.

During the BEXUS-12 mission temperature data were received every 30 seconds as part of the housekeeping data package. Before the launch the temperatures increased because of the very good thermal insulation and the dissipation of the electronics. After the launch the external temperature decreased fast and the temperatures measured inside decreased also after a peak value.
Thermal calculations were performed for the BEXUS flights [11]. The power consumption of the experiment was about 3.5 W (3 W from the TRITEL instrument and about 0.5 W from the rest of the electronics). According to the thermal model developed it results a temperature difference of 37.6 °C between the TRITEL electronics located inside and the external air temperature for the BEXUS flight. It is close to the values measured during the BEXUS flights (see Tab. 3).

3.3 Electronics design

According to the experiment setup (see Fig. 7.) the active instruments can be divided into several major parts. The basic operational concepts and principles will be presented in the follows.
The experiment is powered by its own battery unit during the mission; therefore no power interface to the gondola was needed. In order to extend the operational time of the Battery Unit, a simple analogue control circuit (Thermal Management Unit) based on a comparator with hysteresis controls the heating of the battery pack.
The Service Module (SM; consist the Power System and the Ethernet converter) has dual functionality: power distribution to and signal connection between the subsystems. In the Service Module the proper

voltage levels are provided by the power supply system for the measurement systems. Latched Current Limiters (LCLs) are used to protect the battery from overload in case of failure of any of the subsystems. Since TRITEL is sensitive to under-voltage supply its internal power supply has to be protected by using an Under-Voltage Lockout (UVLO) circuit, which turns off the LCLs when the voltage of the battery decreases to 15.5V.

4. TECHNOLOGICAL MONITORING DURING THE FLIGHTS

During the flight of the BEXUS-12 and BEXUS-14 the communication was continuous between the ground control of the experiment team and the experiment itself. Housekeeping (HK) data were received every 2 minutes, time and energy spectra every 10 minutes from TRITEL. The GM counters provided time spectra every 10 minutes.
The input voltage and the input current of the TRITEL instrument were monitored and found to be stable during the flight. The temperature of the Battery Unit was also monitored during the flight. The values measured showed that the heating of the Battery Unit was adequate.
TRITEL had nine temperature sensors inside. Seven additional temperature sensors were located in different parts of the experiment. The identification of the temperature sensors used can be found in Tab. 3.

Table 3. Temperature sensors and the temperature ranges measured.

ID of the sensor	Location of the sensor	Measured temperature range (°C)	I∆TI (°C)
EXT	Outside environment	11.5 – -54.5	66
TriTel_X	TRITEL X axis detector	17.5 – 32	14.5
TriTel_Y	TRITEL Y axis detector	17.5 – 31.5	14
TriTel_Z	TRITEL Z axis detector	18 – 32	14
TriTel_ADC_X	TRITEL X axis ADC*	17.5 – 34.5	17
TriTel_ADC_Y	TRITEL Y axis ADC	18 – 35	17
TriTel_ADC_Z	TRITEL Z axis ADC	17.5 – 35	17.5
TriTel_CPU	TRITEL CPU** Panel	18.5 – 32	13.5
TriTel_PS	TRITEL Power Supply Panel	17 – 30	13
TMP_BAT	In the Battery Unit	13 – 18	5
TMP_GM1T	On the cover of GM1	-5 – 17.5	22.5
TMP_GM1E	On the HV panel of GM1	6.5 – 28	21.5
TMP_GM2T	On the cover of the GM2	-8 – 19.5	27.5
TMP_GM2E	On the HV panel of GM2	4 – 31.5	27.5
TMP_EPS	On the EPS*** panel of the TECHDOSE experiment	19.5 – 35.5	16

* ADC: Analog-to-Digital Converter

** CPU: Central Processing Unit

*** EPS: Experiment Power System

All the parts of the experiment were in the nominal working temperature range [11] during the flight.

5. PRELIMINARY SCIENTIFIC RESULTS

The floating altitude of the BEXUS flight was 27-29 km and the balloon was floating for about 2 hours. During this time 12 primary and 12 coincidence 10-minute-long spectra were received for each telescope.
In the experiment setup the Y-axis of the TRITEL instrument pointed towards the zenith direction. The X- and Z-axes were orthogonal to the Y-axis and parallel with the side walls of the gondola. The effective thickness of the shielding in front of the detectors was ~0.5-0.6 g/cm^2 aluminium.
The dose rates measured with TRITEL X-axis and with one GM counter can be seen in Fig. 9.

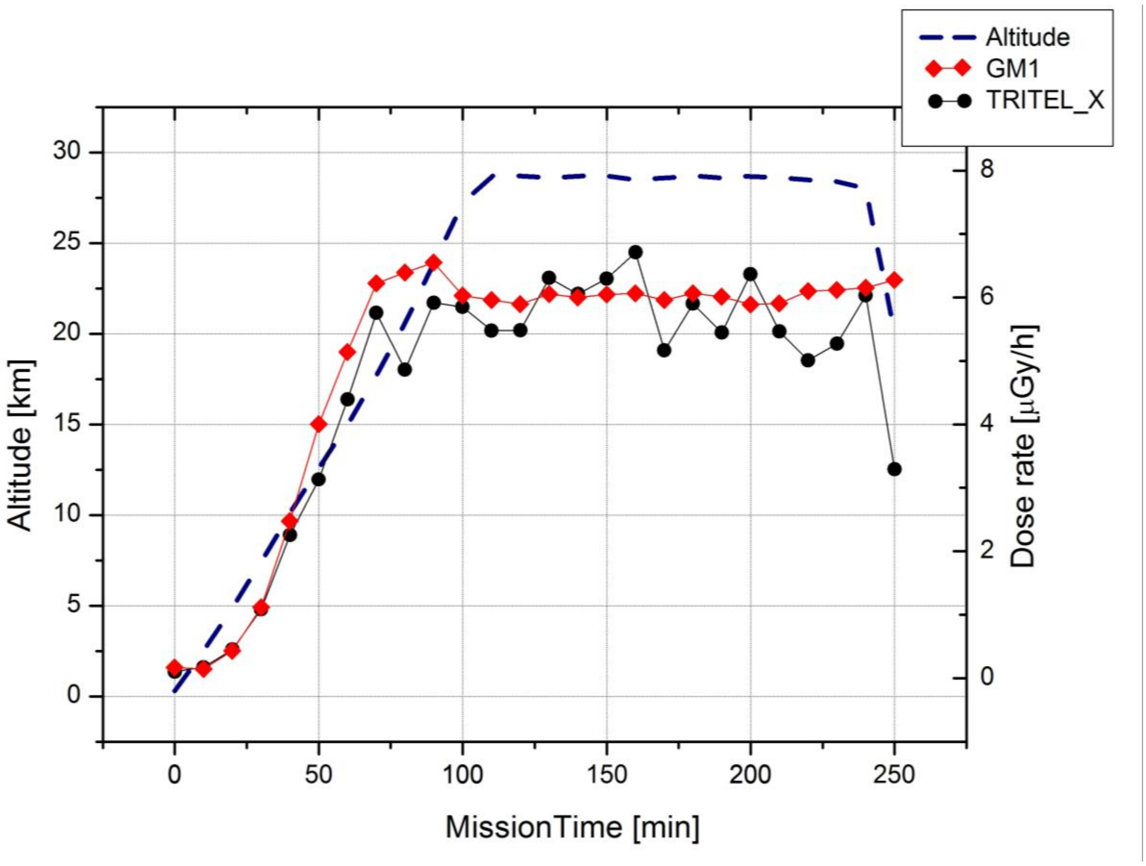

Figure 9. The dose rate profile for a BEXUS flight with a floating altitude of 28.6 km (BEXUS-14).

The energy calibration of the TRITEL telescope was performed with an ^{210}Po alpha-source (E_α = 5.3 MeV), and a ^{241}Am alpha/gamma source (E_γ = 59 keV). The GM counters were calibrated in gamma radiation field using ^{137}Cs source. During the flights the count rates were observed with the GM counters and based on the calibration estimation were given of the possible dose rates. It is only an estimation since there are in the stratospheric radiation field several other high LET particles than photons (such as muons,…).

The Fig. 9 shows the so-called Pfotzer-maximum [12] at an altitude range of about 21-22 km (see the GM1 red curve). From previous studies it is well known that this is the maximum of the secondary particle production. The altitude of the maximum varies with the geographic latitude and at the location of the ESRANGE base (67° N, where the magnetic cut-off rigidity of the Earth's magnetosphere is below 1 GV) the measured value is in good agreement with earlier measurements [13].

The measured average dose rate was about 6 μGy/h at an altitude of 28.6 km (see Fig. 9). The total absorbed dose for the whole flight (ascent, float, descent) in case of the TRITEL three axes in average was 19.9 ± 1.0 μGy and the measured average absorbed dose in case of the Pille dosimeters was 15.6 ± 1.1 μGy. The absorbed doses measured with TRITEL for the balloon flight are higher than the one measured with Pille, as it was expected due to the low sensitivity of TL detectors to particles with LET higher than 10 keV/μm.

The further scientific data evaluation is on-going and will be presented at later stages.

6. CONCLUSIONS

The Hungarian COCORAD and TECHDOSE student teams were selected to take part in the BEXUS project and designed, built and carried out a scientific experiment on board a stratospheric research balloon. The technological platform developed in the frame of the programme. This platform consist active and passive instruments to detect the cosmic radiation using stratospheric research balloons. The COCORAD experiment used first time in real mission conditions the TRITEL 3D silicon detector telescope to measure the cosmic radiation and its dose contribution during the BEXUS balloon flight. It was also the first time that an intercomparison between the results of measurements performed with the Pille TL dosimeter system and the TRITEL 3D telescope was provided. Further scientific data evaluation is in progress and will be presented at later stages.

7. ACKNOWLEDGEMENTS

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