RADIATION MEASUREMENT ON A BEXUS BALLOON

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ABSTRACT

The Earth is permanently exposed to energetic particle radiation from cosmic rays. This cosmic particle radiation yields, together with its secondary particles produced in the Earth's atmosphere, a natural radiation field inside the atmosphere. This complex radiation field is composed of charged and neutral particles. The charged particles are mainly protons, alpha-particles, electrons, muons, and some heavy nuclei. The neutral components are neutrons and gamma-rays. The radiation exposure is dependent on altitude and geomagnetic latitude because the radiation field is modulated by Earth's magnetic field. The scientific goal is to investigate the dose rate dependence on the altitude at near solar minimum conditions in high latitudes. For this investigation a particle telescope consisting of four segmented silicon semiconductor detectors was developed. Due to the arrangement of the detectors, it is possible to separate neutral and charged particles and the calculated dose rates can be converted into a dose equivalent rate which is the unit for radiation protection. The Flight Radiation Environment Detector (FRED) will make measurements onboard a stratospheric balloon as part of the BEXUS programme. Because of the relatively slow rate of climb of the BEXUS balloon we can investigate the dose rate in dependence on the altitude up to 35 km in a single flight. In particular we will be able to measure below, in and above the Pfotzer maximum.

1. INTRODUCTION

As the sun is currently close to solar minimum conditions, there is a higher cosmic ray flux than at solar maximum. This can be seen in Neutron Monitor count rates [1]. The goal of the described experiment is to measure the dose rate in dependence of the altitude in the complex radiation field of Earth. The launch site of the balloon is at Esrange near Kiruna in north of Sweden. This area is well suited for this investigation as in the polar region there is the highest particle flux of galactic cosmic rays at Earth because there is a low geomagnetic cutoff [2]. Therefore, we have the highest dose rates in this region [3] and we can use the measurements as conservative estimation for the whole Earth.

The Extraterrestrial Physics department at the University of Kiel performs longterm-measurements onboard the International Space Station (ISS) and onboard aircraft with silicon detectors [4][5][6]. Thereby, it is possible to perform simultaneous measurements in different altitudes and to compare the data. We have data for an altitude range of 10 to 14 km from measurements onboard aircraft. By using a balloon we can investigate the radiation field from ground up to 35 km and back to the ground in one time series. In addition, we can compare these balloon measurements with measurements on-board the ISS, orbiting in 350 km altitude. The advantage of this experiment is a neutral channel so that we can investigate both the neutral and the charged component of the secondary comic rays with one experiment. The sensor head consists of 4 silicon detectors which are arranged in a telescope geometry.

2. THE BEXUS PROGRAMME

BEXUS (Balloon-borne Experiments for University Students) is a German-Swedish student programme [7]. This programme offers opportunities for students to conduct scientific and technological experiments on research balloons under special atmospheric conditions. The BEXUS programme is realised under a bilateral Agency Agreement between the German Aerospace Center (DLR) and the Swedish National Space Board (SNSB). Therefore, German and Swedish students each have access to 50 percent of the balloon payload. The Swedish share of the payload has been made available to students from other European countries through a collaboration with the European Space Agency (ESA). The duration of the project is approximately 1 year. The stratospheric balloons are flying unguided and reach a maximum altitude of 35 km. The flight duration is 2-5 hours, depending on wind and weather conditions. The launching site is located near Kiruna in the north of Sweden, on the European launching site for rockets and balloons, Esrange Space Center. The BEXUS 11 launch was on the 23.11.2010.

3. THE FLIGHT RADIATION ENVIRONMENT DETECTOR (FRED)

The experiment FRED mainly consists of 3 components. These are the Detector Stack, the Irena, and the Power

Proc. '20th ESA Symposium on European Rocket and Balloon Programmes and Related Research'
Hyère, France, 22–26 May 2011 (ESA SP-700, October 2011)

board. The Detector Stack is made up of 4 segmented silicon semiconductor detectors which are arranged in a telescope geometry with an opening angle of 120 degrees. Due to this geometry we can determine the Linear Energy Transfer (LET) by using coincidence condition. From the LET we can determine an average quality factor by using the ICRP 60 functions [8]. With this average quality factor we can convert the dose in silicon into a dose equivalent which is the unit for radiation protection as the dose equivalent includes the biological effectiveness of the radiation. Figure 1 shows a schematic drawing of the Detector Stack. The detector thickness is 300 µm - for all detectors - and the active area is square with a 30 mm edge length. The detectors B, C, and D are glued together as close as possible (depending on necessary distances for cables), to form a sandwich detector, as the detectors B and D and the outer segment of detector C will be used as anticoincidence for the neutral particle channel (grey area in Figure 1), which forms the inner part of detector C. The detectors will be connected to the Power board over a filter board. Furthermore, the detector signals circuit will be connected over the filter board to the Irena which is used to handle the data processing and storage. It is made up of 2 PCBs, the analogue and the digital board. Figure 2 shows a schematic drawing of the whole experiment.

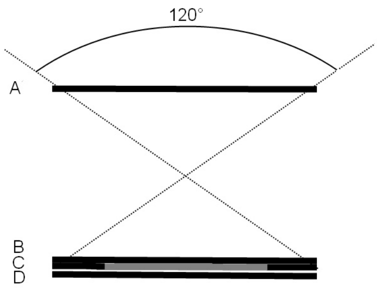

Figure 1. Schematic of the arrangement of the detectors

An incoming particle interacts with the silicon in the Detector Stack. Thereby, free charge carriers are created. The Charge Sensitive Amplifier (CSA) collects these free charge carriers and converts them into a voltage pulse. The voltage pulse will be shaped and amplified with two different amplifier steps. This voltage pulse is read out by the Analogue Digital Converter (ADC). The Field Programmable Gate Array (FPGA) reads out the ADC signal and determines the pulse height. If the ADC, which is reading out the voltage pulse with the high amplification, is over range than the FPGA is analysing the ADC with the low amplification. The processor stores the pulse height on the Secure Digital card (SD card). Furthermore, data is sent from the processor to the Bexus E-Link per UDP protocol because we have an up- and downlink connection to the experiment.
The CSA operates in two gain levels. The two gain levels are high and low gain. The energy range for the high gain is from 75 keV up to 18 MeV and for the low gain from 1 MeV up to 280 MeV. That means we can measure the energy loss in silicon from 75 keV up to 280 MeV.

There is also a pressure sensor on the Irena board. The purpose of this sensor is to stop the writing on the SD card in the descent phase of the balloon when an air pressure of 800 mbar is reached.
The Power board will be connected to the BEXUS battery pack. This board is creating the -50 V detector bias voltage for the Detector Stack. Furthermore, it will be managing the different powers for the components. The ethernet connector for the downlink is also situated on this board.
The housing of the experiment is made of magnesium. The height of the housing is 99.5 mm, with a footprint on the plate of 112 mm x 100 mm. Figure 3 shows a picture of FRED.

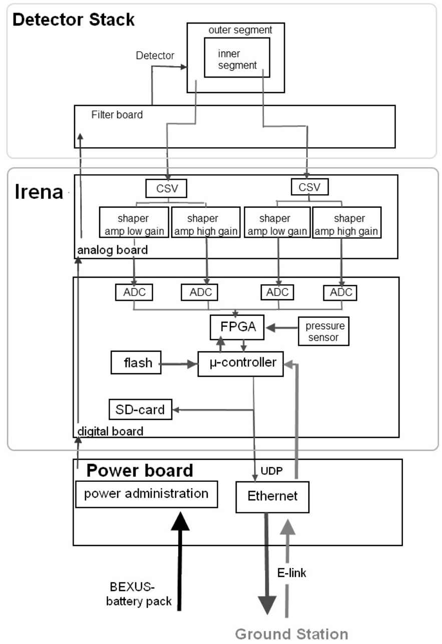

Figure 2. Schematic of the electronics

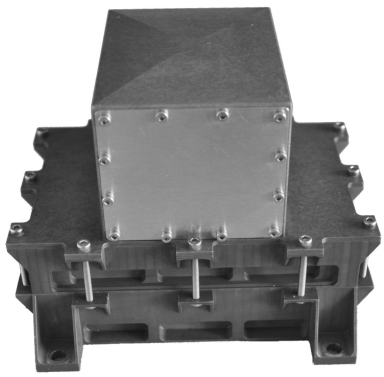

Figure 3. The Flight Radiation Environment Detector

4. THE MEASUREMENT ON THE BEXUS 11 BALLOON

Figure 4 displays the count rate profile in counts per minute in dependence on the altitude from the inner segment of the B detector. One can see that there is only data available for altitudes up to 8.5 km. The reason for this is that the down link broke up at this altitude. The data was also stored on an SD card but after recovery of the instrument the SD card could not be read out so that all data above 8.5 km was lost. We think a possible cause for the damage might have been the impact of the gondola. For the next flight we have changed the design. The most important changes are that we have integrated a pressure sensor, as well as a second mode into the software. Now we have an ascent and descent mode in the software. At the beginning of the measurement the instrument is in ascent mode, if the pressure reaches a value of 200 mbar the software switches into descent mode. If now the pressure reaches a value over 800 mbar the instrument stops the measurement and the writing on the SD card.
Nevertheless the instrument showed a very good performance up to 8.5 km altitude. From our data we can calculate the dose rate in silicon for different altitudes. The definition of the absorbed dose D is energy loss dE per mass unit dm [8]

$$\mathrm{D} = \frac{\mathrm{dE}}{\mathrm{dm}}. \quad (1)$$

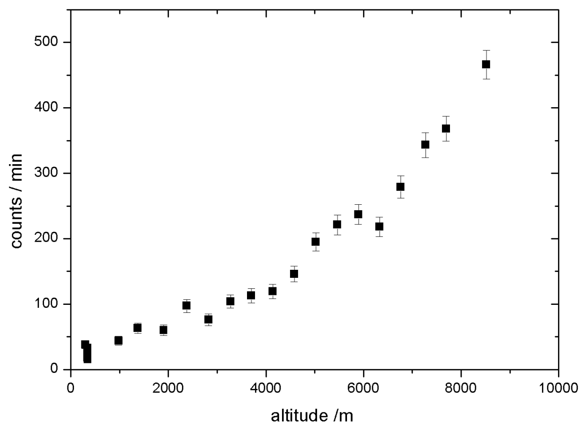

Figure 4. The count rate in the B detector during the first phase of the BEXUS 11 flight.

Dose rate means dose per time. Figure 5 shows the altitude dependence of the dose rate up to 8.5 km as measured in the inner segment of the B detector. We can calculate energy-loss spectra for neutral and charged particles. These are shown in Figure 6. These spectra were calculated for the whole flight data. The statistics are rather poor due to the fact that there are only 20 minutes of data available. Nevertheless neutral and charged particles can be seperated.
The calculation of the LET for the determination of the mean quality factor is not reasonable due to the rather poor statistics in channels over 1 MeV energy loss. As a first estimate the energy loss of 1 MeV in 300 µm Si equates to an LET of 4 keV/µm. Charged particles with an LET lower than 10 keV/µm have a quality factor of 1. Due to this the mean quality factor equals 1 for the charged particles in this measurement.

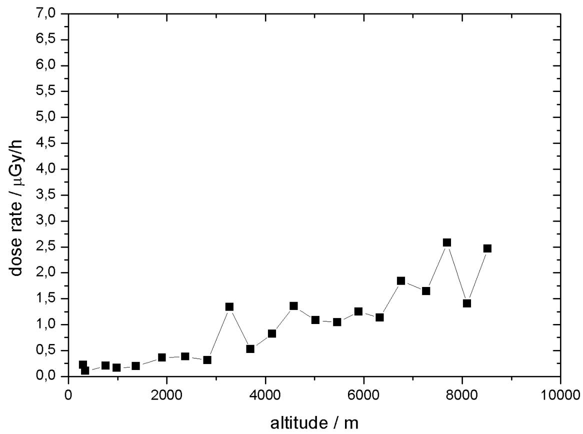

Figure 5. Dose rate in silicon versus altitude altitude for the B-detector

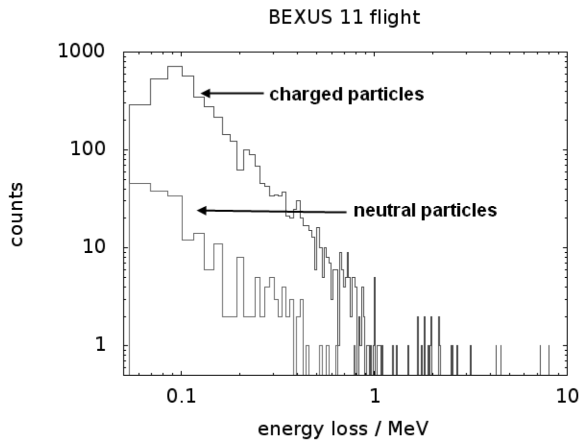

Figure 6. The neutral and charged particle energy loss spectra up to an altitude of 8.5 km.

5. CONCLUSION

We have build a new instrument based on silicon detectors for the investigation of the altitude dependence of the dose rate. We have flown the instrument on the stratospheric balloon BEXUS 11 but could only gather data for the first 8.5 km of the ascent phase. Nevertheless, the detector shows a very good performance up to this altitude. We have demostrated that the measurement principle works as we can distinguish between charged and neutral particles.
For the next flight we have integrated a pressure sensor so that we can stop the measurement automatically before the gondola reaches the ground.

ACKNOWLEDGMENTS

This experiment was carried out as a part of the REXUS/BEXUS programme. The REXUS/BEXUS programme is realised under a bilateral Agency Agreement between the German Aerospace Center (DLR) and the Swedish National Space Board (SNSB). The Swedish share of the payload has been made available to students from other European countries through a collaboration with the European Space Agency (ESA). EuroLaunch, a cooperation between the Esrange Space Center of the Swedish Space Corporation (SSC) and the Mobile Rocket Base (MORABA) of DLR, is responsible for the campaign management and operations of the launch vehicles. Experts from DLR, SSC and ESA provide technical support to the student teams throughout the project.
The authors thank the Extraterrestrial Physics department at the University of Kiel for their support and for the realisation of the project. Especially Stephan Boettcher, Bjoern Schuster and Lars Seimetz for the technical support and Soenke Burmeister, Professor Robert F. Wimmer-Schweingruber and Professor Bernd Heber.

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