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THE HUNGARIAN COCORAD EXPERIMENT IN THE BEXUS PROGRAM OF THE ESA

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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 Hungarian CoCoRAD Team was selected to take part in the BEXUS (Balloon Experiment for University Students) 12&13 project. In the frame of the BEXUS programme Hungarian students from the Budapest University of Technology and Economics carried out a radiation and dosimetric experiment on a research balloon, which was launched from Northern Sweden in September 2011.

The central part of the experiment was the TriTel 3-dimensional silicon detector telescope which was originally developed for cosmic radiation and dosimetric measurements on board the International Space Station. In the frame of the CoCoRAD experiment the TriTel were modified and extended with additional mechanical, thermal and electrical parts to make it able for operating on board the BEXUS stratospheric balloon system.

During the development process the relatively hard environmental conditions were taken into account, like the very high accelerations during the flight profile of the balloon, the very low outside temperatures in the stratosphere (can be -90°C) and the electrical interface requirements between the experiment and the BEXUS balloon own communication system.

This paper presents the brief overview of the CoCoRAD experiment objectives, the description of the used mechanical protection against the high accelerations, the applied thermal model for the experiment and its verification results from the flight of the BEXUS-12.

I. THE BEXUS PROGRAMME AND THE COCORAD STUDENT EXPERIMENT

Among many other student projects ESA Education Office announced a call for proposals for the REXUS 11/12 and the BEXUS 12/13 flights for university students in 2010. 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].

A Hungarian student team were selected for the first time to take part in the BEXUS 12/13 project of the European Space Agency Educational Office. The name of the experiment was CoCoRAD, an abbreviation for Combined TriTel/Pille Cosmic RADiation and Dosimetric Measurements. The experiment flew on board the BEXUS-12 stratospheric balloon on the 27th of September 2011 from ESRANGE Space Center. The CoCoRAD experiment used the TriTel three dimensional silicon detector telescope for active monitoring and several Pille thermoluminescent dosimeters in order to study the usability of the Pille passive dosimeter system during stratospheric balloon flights. Both the Pille and the TriTel space dosimeter system have been developed in the former KFKI Atomic Energy Research Institute (MTA Centre for Energy Research from 1 of January 2012). The present paper addresses the main objectives of the CoCoRAD experiment, the description of the used mechanical protection against the high accelerations, the applied thermal model for the experiment and its verification results from the flight of the BEXUS-12.

II. INSTRUMENTATION USED IN THE COCORAD EXPERIMENT

The CoCoRAD experiment used two different types of measurement system during the flight of the BEXUS-12 balloon. One of them was an active space dosimetry system, the TriTel three-dimensional silicon detector telescope and the other one was the Pille passive thermoluminescent (TL) dosimetry system. In the following sections a short overview of these two instruments is given.

II.I The TriTel dosimetry system

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. 1).

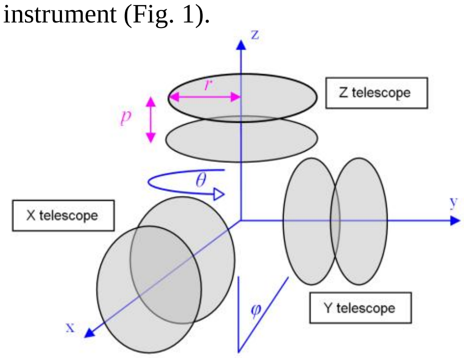

Fig. 1: The 3D telescope geometry (*r* is the radius of the detectors, *p* is the distance between two detectors in the telescope)[2].

By evaluating the deposited energy spectra recorded by TriTel the absorbed dose, the LET (Linear Energy Transfer) 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 LET spectra in silicon will be 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 (Fig. 1).

The effective surface of each detector is 220 mm^2 with a nominal thickness of 300 µm.

II.II The Pille Space Dosimetry System

The development of the Pille thermoluminescent dosimeter system started 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 is designed for spacecraft: it is a small, light-weight device with a 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[3].

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.

III. THE OBJECTIVES OF THE COCORAD EXPERIMENT

Table 1 contains the primary (1), the secondary (2) and the tertiary (3) experiment objectives of the CoCoRAD experiment.

Exp. obj. #	Description of the objective	Priority
Obj.1	To perform dosimetry measurements with the TriTel 3D silicon detector telescope at altitudes up to maximum 35 km	1
Obj. 2	To measure the excess absorbed dose of the BEXUS balloon mission with the Pille thermoluminescent dosimeters	1
Obj. 3	To intercompare the results of the measurements	1
Obj. 4	To use TriTel data for improving the Pille results (correction)	1
Obj. 5	To measure the altitude dependence of the dose rates and LET spectra with TriTel	2
Obj. 6	To monitor first time the working of the TriTel detector in real mission conditions	2
Obj. 7	To estimate the possible altitude of the Pfotzer maximum based on the measured data	3

Table 1: CoCoRAD experiment scientific objectives.

IV. MECHANICAL DESIGN

The mechanical design shall fulfil the design requirements according to the vibration profile of the gondola and the very high accelerations present mainly during landing. The experiment box shall withstand the 8 m/s landing velocity and the design loads +/-10 g in the vertical direction and +/-5 g in the horizontal directions[4]. Fig. 2 and Fig. 3 show the acceleration profile during the cut and the landing of the BEXUS balloon.

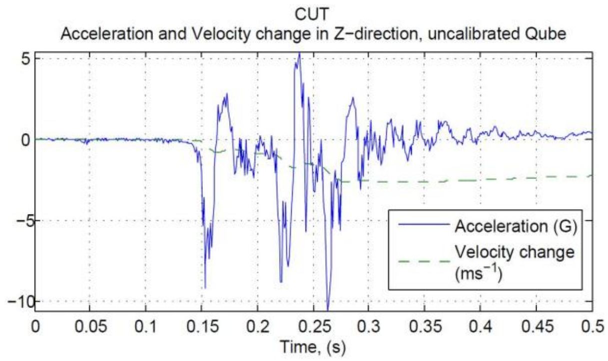

Fig. 2: Acceleration and change in velocity in the Z-direction during the CUT[5].

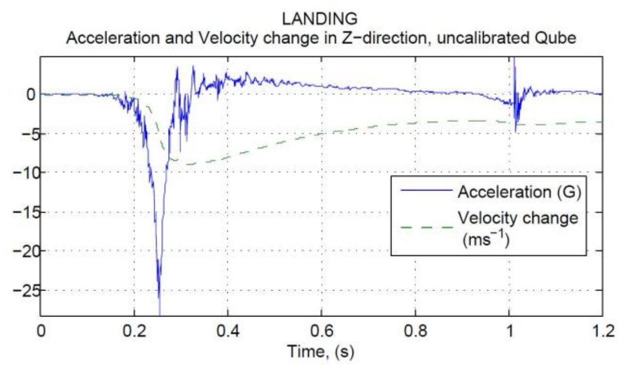

Fig. 3: Acceleration and change in velocity in the Z-direction during the LANDING[6].

These diagrams show the worst case acceleration profile. 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. 4).

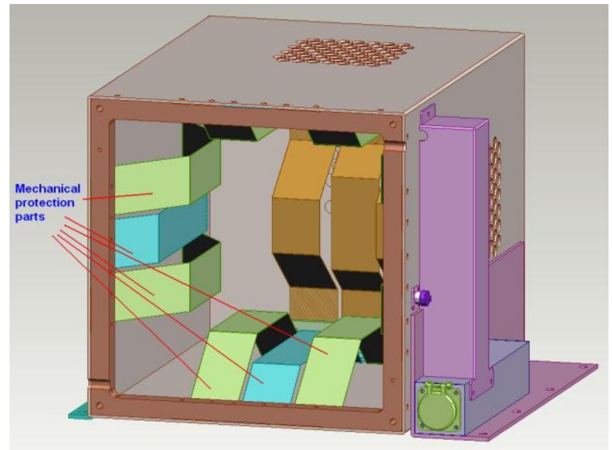

Fig. 4: The mechanical protection inside the Experiment Unit.

Measurements were performed to verify the mechanical protection. We measured the deformation of one protection part due to different accelerations applied between 0g and 5g. The results can be seen on Fig. 5.

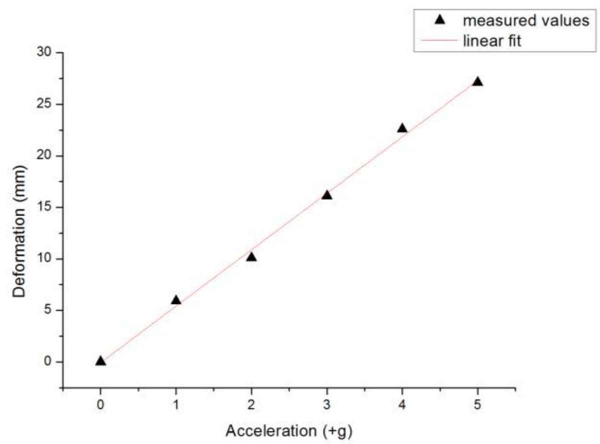

Fig. 5: The deformation of the protection part as a function of the acceleration.

The details of the linear fit on the deformation can be found in Table 2 below.

Equation	$y = a \cdot x + b$		
Adj. R-Square	0.9963		
		Value	S. Error
	Intercept	-0.052	0.0045
	Slope	5.474	0.1491

Table 2: Linear fit results on the deformation.

The deformation proved to be almost linear as a function of the acceleration (see Fig. 5 and Table 2). Based on the linear fit the maximum acceleration which the mechanical protection part can withstand is about +/-8g. In each direction three spring steel will be used. Two of them can withstand individually +/-8g and between them a third stronger one take place for the cases of more extreme accelerations, which are not included in the BEXUS flight requirements[7] (see Fig. 4). These parts together will be able to fulfil the design requirements.

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

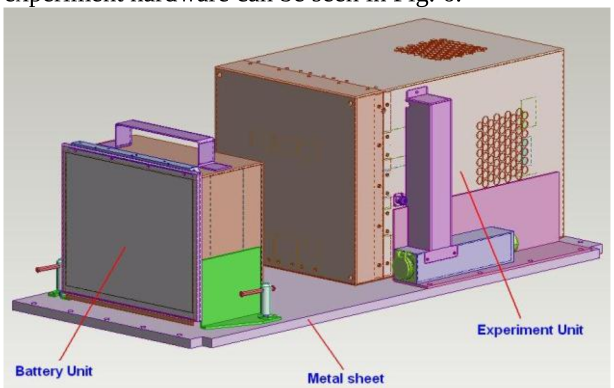

Fig. 6: The mechanical design of the CoCoRAD experiment.

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.

V. THERMAL DESIGN

Since the stratosphere is a very hard environment with very low temperatures we should use relevant thermal design to protect the CoCoRAD experiment during the flight of the balloon.

V.I The expected thermal conductivity

First of all we made calculations about the expected thermal conductivity through the mechanical interfaces parts of the experiment.

The Experiment Unit has double protection. The external box is provided with protection against the very high accelerations during the mission and the landing. The units located inside this box are covered with thermal insulation to protect the hardware against the very low temperatures. The exterior box is mounted to the metal sheet with brackets made of aluminium (Fig. 6). The thermal conductivity of the aluminium is 237 W/mK.

The fixing method of the Experiment Unit was applied by brackets. The thickness of the brackets is 3 mm and they are made of the same aluminium alloy as the exterior box itself. The expected thermal conductivity between the metal sheet and the experiment outer box can be expressed by using the equation of thermal conductivity[8]:

$$j = -\lambda \cdot gradT, \qquad [1]$$

where j is the thermal current density (W/m^2), and λ is the thermal conductivity (W/mK). In the case of our calculations the equation can be approximated by:

$$j = -\lambda \cdot \frac{dT}{dx}, \qquad [2]$$

where dx is the thickness of the brackets in metres and dT is the temperature difference between the metal sheet and the outer box of the experiment in Kelvin. Equation 3 describes the loss of thermal power (Q):

$$Q(dT) = j \cdot A = -\frac{\lambda \cdot A}{dx} \cdot dT \approx -960 \cdot dT[W], \qquad [3]$$

where A is the surface where the thermal energy can flow. According to Equation 3 the temperature of brackets and the metal sheet will be the same due to the very good thermal conductivity of the brackets. We can conclude that the temperature of the outer box will be equal with the outer temperature because of the very good thermal conductivity of the brackets used.

The same calculation can be used for the Battery Unit too. In this case Equation 3 can be written as follows:

$$Q(dT) \approx -245 \cdot dT \qquad [4]$$

The thermal conductivity will be smaller for the Battery Unit because of the smaller contact areas, however we can conclude that the temperature of the Battery Unit will be also equal to the outside temperature too.

V.II The thermal design and the calculated possible temperature ranges

To calculate the expected temperature of the units located inside the experiment box, first an estimate of the possible outside temperature range has to be given.

During the integration the expected outside temperature will be about 20±5°C[9]. In this phase TriTel will be switched on and the dissipated electrical power inside the experiment box will be 4-5 W. This dissipation has three main sources: the TriTel detector will provide about 3-3.5 W, the electronics of the power system will dissipate about 0.5 W and the Ethernet converter will dissipate about 0.7 W.

The thermal insulation will be designed such that the maximum temperature inside the TriTel can't be higher than 45°C and the minimum temperature can't be lower than -40°C. After the integration the temperature before the launch of the balloon will be about -20°C and during the mission it can reach -60°C too (the possible minimum is -90°C). Table 3 shows the average temperature of the atmosphere at 60°N latitude as a function of the altitude[10].

Altitude (km)	Temperature (Dec-Jan, °C)	Temperature (Dec-Jan, °C)
0	-17	7
5	-33	-14
10	-56	-47
15	-56	-47
20	-59	-47
25	-61	-44
30	-58	-36
35	-55	-24
40	-44	-12

Table 3: The temperature of the atmosphere at 60°N latitude as a function of the altitude.

We can provide a calculation using a simplified model of the Experiment Unit. This model can be seen in Fig. 7.

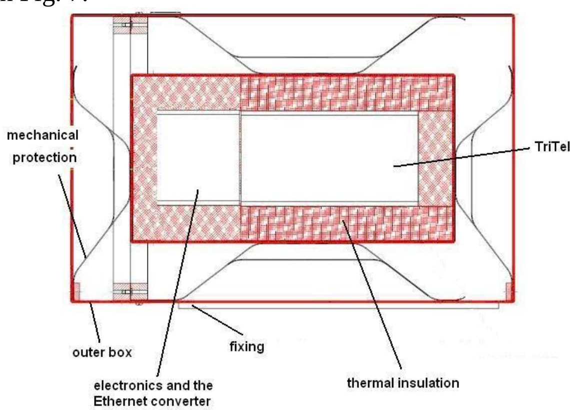

Fig. 7: The simplified thermal model of the Experiment Unit.

In this model we suppose that the temperature of the outer box, the temperature of the mechanical protection and the temperature of the box located inside will be equal to the temperature of the rails of the BEXUS balloon gondola. We have already shown that the temperature of the exterior box and the temperature of the environment will be equal. The mechanical protection of the Experiment Unit is provided with spring steel sheets covered with a very thin layer of felt. We can suppose that the thermal energy will flow through the mechanical protection parts due to the good thermal conductivity of the steel sheets.

The thermal insulation will be made of environmentally friendly extruded polystyrene (XPS), which has a very low thermal conductivity: 0.031 W/mK. The average thickness of the insulation is 3 cm. An important advantage of this type of insulation is that it is almost watertight 0.2% for permanently immersing it into water (it can be important in case of landing into a lake).

The average power dissipation inside the box will be 4.5-5.5 W.

Using the thermal conductivity equation the expected thermal difference between the outer parts (the rails of the gondola) and the main internal parts can be calculated in the case of thermal balance.

$$Q(dT) = -\frac{\lambda \cdot A}{dx} \cdot dT \cong -0.093 \cdot dT\ [W] \,, \qquad [5]$$

where λ=0.031 W/mK, dx=3 cm and A=0.09 m^2 (the surface of main parts located inside in the model used). In Equation 5 Q(*dT*) means the energy dissipated inside and *dT* gives us the temperature difference. Table 4 shows the temperature difference for different values of dissipated power between 4.5-5.5 W.

Dissipated power Q (W)	Temperature difference |dT| (°C)
4.5	48.39
4.6	49.46
4.7	50.54
4.8	51.61
4.9	52.69
5.0	53.76
5.1	54.84
5.2	55.91
5.3	56.99
5.4	58.06
5.5	59.14

Table 4: The temperature difference as a function of the dissipated power in the case of the Experiment Unit.

Table 4 shows that the expected temperature difference between the outside environment and the main internal parts will be between 48-59 °C with an average value of about 54 °C.

Inside the TriTel box no thermal heaters will be used. The thermal insulation and the dissipated energy of TriTel and the other electronics parts will be enough to provide the optimal temperature balance.

Using the insulation and assuming that the power dissipated is 4.5-5.5 W the temperature of the TriTel will be between 30°C and -40°C during the flight of the balloon. Under a temperature of 30°C the electrical noise of the system is optimal for the measurements and over -40°C the electronics of TriTel was already tested.

Since Pille dosimeters are passive, they do not dissipate energy. Pille is able to perform measurements in the possible temperature range of the BEXUS mission. We confirmed this with thermal vacuum measurements.

Problem might occur only inside the integration building where the outer temperature will be about 20±5°C[11]. After switching on the CoCoRAD experiment the temperature will increase up to 60-70 °C when it reaches thermal balance. The time needed for this depends on the thermal inertia of the experiment box. We studied this thermal inertia with vacuum chamber measurements and based on the results we used some holes and cavities in the thermal insulation (see Fig. 8). With the size and the number of the holes we can ensure that the temperature of the TriTel do not increase fast in the 20±5°C environment (during the integration the conductivity of the air will be significant through the holes).

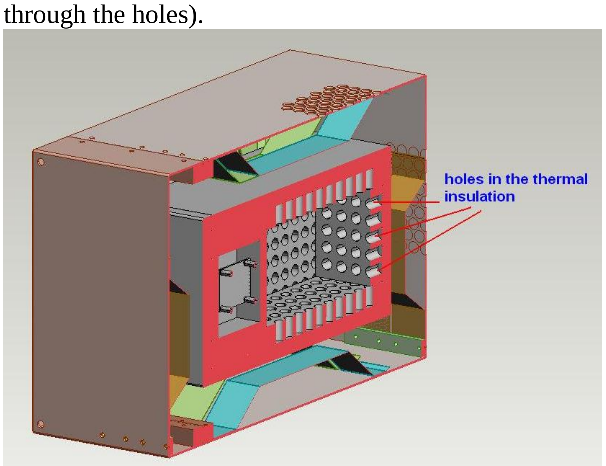

Fig. 8: The holes in the thermal insulation.

After the integration phase outside the building the temperature will be much lower. In this environment the expected temperature of the TriTel will be 30°C maximum, which is already optimal for the measurements, however we don't want to provide measurements at the surface (if the temperature of the detectors are smaller than the electronic noise is lower and the efficiency of the measurements are better).

During the flight the temperature will decrease outside and inside too. In the case of an external temperature of -80 °C we expect -30°C inside the box. During the whole flight the expected temperature of TriTel will be between 20°C and -30°C. In this range the noise of the detectors are low enough to measure the energy deposited by relativistic protons. During the flight the density of the atmosphere is very low (at the top of the flight trajectory the pressure is only about 10 mbar). This means that the conductivity of the atmosphere through the holes can be neglected and the experiment will not lose thermal energy through the holes.

In the case of the Battery Unit the batteries will have their own thermal sensors and heaters to provide the most sufficient temperature range for the optimal efficiency of the batteries. The Battery Unit and its thermal insulation can be seen in Fig. 9.

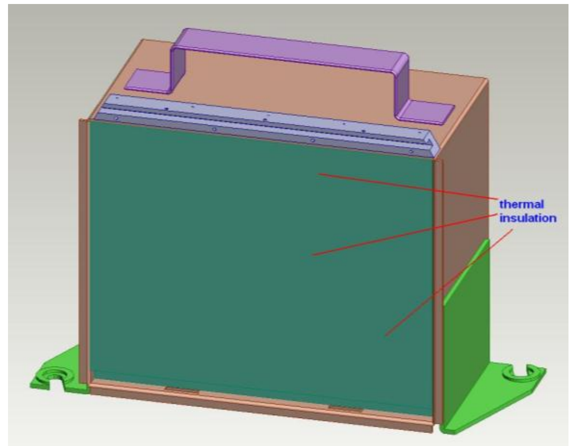

Fig. 9: The thermal insulation of the Battery Unit.

In this case the thermal insulation will be the same with an average thickness of 3.75 cm. The thermal conductivity equation is

$$Q(dT) = -\frac{\lambda \cdot A}{dx} \cdot dT \cong -0.0438 \cdot dT \; [W] \quad [6]$$

where λ=0.031 W/mK, dx=3.75 cm and A= 0.053 m^2 (the estimated surface of the batteries).

Table 5 shows the temperature difference in the case of different dissipated thermal power.

Dissipated power Q (W)	Temperature difference |dT| (°C)
0.0	0.00
0.2	4.57
0.4	9.13
0.6	13.70
0.8	18.26
1.0	22.83
1.2	27.40
1.4	31.96
1.6	36.53
1.8	41.10
2.0	45.66

Table 5: The temperature difference as a function of the dissipated power in the case of the Battery Unit.

The dissipation of the thermal heaters will be controlled by the thermal sensors to provide the temperature of the batteries in the optimal temperature range.

V.III Verification of the thermal design by tests

The thermal insulation parts of the experiment were built together and TriTel was inserted into them. The thermal insulation parts were glued by Soudal industrial universal glue. The glue is chemical tolerant between -30°C and +70°C.

TriTel has several temperature sensors (thermistors) inside the instrument. The measured temperature data can be downloaded as HK data by using the TriTel software. The most important one is the temperature of the detectors, because the electrical noise of the detectors depends on it. Inside TriTel three mutually orthogonal silicon detector telescopes are located. Each of them has its own thermistor. The temperatures measured by the thermistors are equivalent to the temperatures of the detectors. TriTel has thermistors on the PSU board, on the microprocessor board and on the three ADC converters (for X, Y and Z axis) as well.

First we measured the temperature of each thermistor inside the laboratory, where the outside temperature was 25°C. Every five minutes we received the temperature data from TriTel. After 75 minutes the temperature of the detectors was 34-35°C, i.e. during the launch preparation and the tests the temperature of the detectors won't be higher than 35-40°C, expectedly, because none of our tests require more than one hour of continuous operation.

After that TriTel was shut down in order to see how fast it will lose its thermal power. After 40 minutes TriTel was activated again and we downloaded the measured HK data. The temperature of the detectors decreased to 30 °C.

Finally TriTel covered with its thermal insulation was put into into a freezing chamber. Inside the freezing chamber the temperature was set to -35°C.

The experiment lasted for almost six hours inside the freezing chamber to test how it will work during a BEXUS flight of typical duration. The lowest temperature measured inside TriTel was -15°C at the end of the tests, which means that the thermal protection has adequate thermal resistance.

The measured data (temperature of the detectors) are plotted in Fig. 10 below.

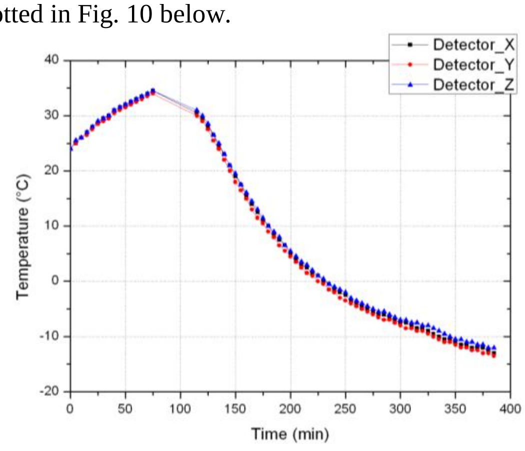

Fig. 10: The measured temperatures of the TriTel detectors.

The temperature values measured at the three telescopes were almost the same during the tests. The maximum temperature was +35°C and the minimum was -14°C. This temperature profile is acceptable for the measurements with TriTel during the BEXUS flight since the thermal inertia of the system is really high.

The temperatures measured at the TriTel Power Supply Unit (PSU), the TriTel Processor Unit (Tproc) and the ADC converters of each detector axis (ADC_X, ADC_Y, ADC_Z) are plotted in Fig. 11.

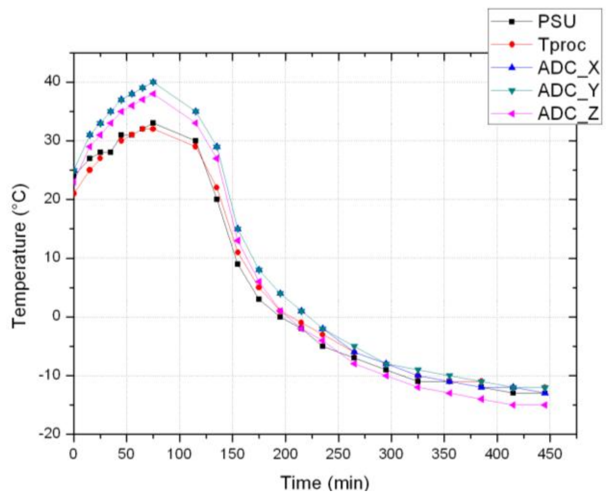

Fig. 11: The temperatures measured at the TriTel electronics units.

Fig. 11 shows that the temperatures measured at different points inside TriTel are again almost in the same temperature range. The temperature of the ADC converters was a little bit higher than that of the PSU and the Processor Unit. The maximum temperature was +40°C and the minimum temperature was -15°C. This temperature profile is also good enough for the measurements with the TriTel during the BEXUS flight.

V.IV Verification of the thermal design by the BEXUS-12 balloon flight

We received during the BEXUS-12 mission with the HK data the temperature data too in every 30 seconds. Since there was a short switch on during the afternoon at the launch day without launch because of the wrong weather conditions we got some interesting temperature results from the experiment on ground. It is important because we used hard thermal insulations for the better thermal balance during the flight which means that possibility of the overheating on ground can be arisen.

The Fig. 12 shows the temperatures inside of the TriTel on ground for an hour long switch on.

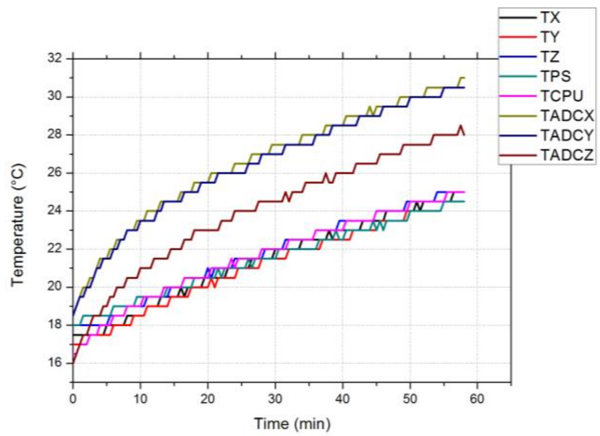

Fig. 12: The temperatures of the TriTel on ground before the launch.

Fitting the following equation:

$$T(t) = A + B \times \exp(-t/C), \qquad [7]$$

to the temperature of each detectors, the average parameters of the fitted curve can be found in Table 6 below. The temperatures of these detectors are the most important because of the thermal noise and we can see that the detector temperatures were separated from several other temperature curves.

	Value	S. Error	R. Error (%)
A	33.97	±1.092	3.2
B	-16.85	±1.059	6.3
C	93.79	±8.180	8.7

Table 6: Fitted curves average parameters for the TriTel detector temperatures on ground.

Fitting the same equation to the hottest electronics parts (TADCX, TADCY), the average parameters of the fitted curve can be found in Table 7 below.

	Value	S. Error	R. Error (%)
A	32.79	±0.264	0.8
B	-13.04	±0.220	1.7
C	33.25	±1.445	4.4

Table 7: Fitted curves average parameters for the TriTel hottest electronics parts on ground.

Table 7 shows that three times longer characteristic time was found in case of the detectors than in case of the ADC converters on ground environmental conditions (where the conductivity of the air should be taken into account).

From Kiruna weather data we known exactly the temperature, air pressure and humidity at the surface for the BEXUS-12 launch day (see Fig. 13).

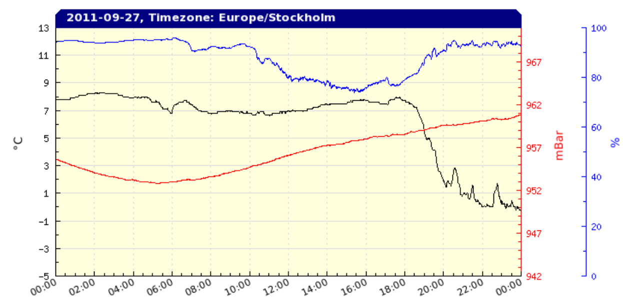

Fig. 13: The outside air temperature, pressure and humidity in Kiruna on ground before the launch day of the BEXUS-12 balloon[12].

The outside air temperature was about 7°C during the afternoon switch on of the experiment. It means that the temperature difference in case of the detectors is about 27±2°C and in case of the ADCs is about 26±1°C in the temperature balance.

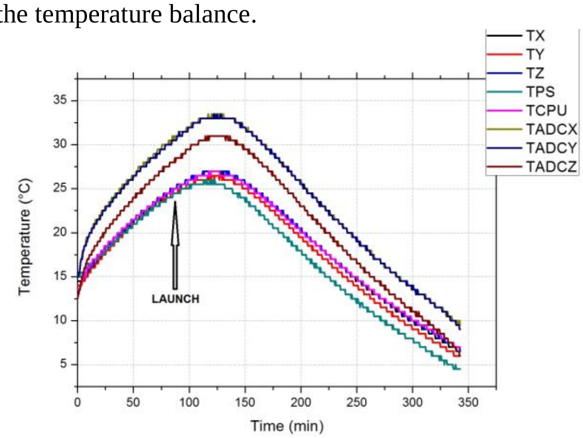

Fig. 14: The temperatures inside the TriTel during the BEXUS-12 mission.

Fig. 14**Hiba! A hivatkozási forrás nem található.** above shows the measured temperatures inside the TriTel during the flight of the BEXUS-12. Before the launch the temperatures increased because of the very good thermal insulation and the dissipation of the electronics. After the launch the outside temperatures decreased fast and the inside measured temperatures decreased also after a maximum peak value.

Fitting the Eq. 7 again to the temperature of each detectors (TX, TY, TZ) after the temperature peak at about 130 minutes on the Fig. 14, the average parameters of the fitted curve can be found in Table 8 below.

	Value	S. Error	R. Error (%)
A	-25.87	±1.136	4.4
B	75.29	±0.847	1.1
C	401.72	±11.117	2.8

Table 8: Fitted curves average parameters for the TriTel detector temperatures during the BEXUS-12 flight.

If we compare the results listed in Table 8 above with the results in case of on ground switch on we can conclude a much longer characteristic time because of the low pressure conditions (almost no atmosphere and humidity).

Fitting the Eq. 7 to the temperature of the hottest electronics parts (TADCX, TADCY) after the temperature peak at about 130 minutes on the Fig. 14, the average parameters of the fitted curve can be found in Table 9 below.

	Value	S. Error	R. Error (%)
A	-33.47	±1.602	4.8
B	91.92	±1.288	1.4
C	450.12	±13.484	2.9

Table 9: Fitted curves average parameters for the TriTel hottest electronics parts during the flight of the BEXUS-12.

The characteristic time is almost the same in case of the detectors and the ADCs.

The outside air temperature was about -63°C during the BEXUS-12 flight (EuroLaunch data). It means that the temperature difference in case of the detectors is about 37±2°C and in case of the ADCs is about 28±2°C in the temperature balance.

In case of the temperatures measured on ground during the afternoon of the launch day we found a little difference between the measured temperature balance and the thermal model calculations. However in the model which was provided for the BEXUS flight the conductivity of the air was neglected. The difference is coming from that point.

VI. CONCLUSIONS

The Hungarian CoCoRAD student team were selected for the first time to take part in the BEXUS project and designed, built and carried out a scientific experiment on board a stratospheric research balloon.

A mechanical design was developed for the BEXUs flight to protect the instrumentations inside against the high accelerations during the flight. After the mission we received all instruments without any damage, which was the final verification of the used mechanical design.

A thermal model calculations were introduced for the BEXUS flight in case of the CoCoRAD experiment. The power consumption of the experiment was about 3.5 W (3 W from the TriTel and about 0.5 W from the other electronics). If we put this value into the thermal model (Eq. 5) then the temperature difference between the inside located TriTel electronics and the outside air temperature for the BEXUS flight is 37.6 °C. It is close to the measured value which was determined during the BEXUS-12 flight. It means that the used thermal model was adequate.

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