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Dose Rate and Flux Measurements During a Travel from Bulgarian Antarctic Base on Livingston Island to Sofia, Bulgaria

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Abstract

The radiation risk spectrometer-dosimeter Liulin-AA performed observations in the Bulgarian Antarctic Base on Livingston Island. The battery-operated device also did continues measurements at the back trip from Livingston Island to Sofia, Bulgaria between 24 of February and March 9, 2024. Different radiation and environment conditions were detected during this journey. The latter starts with few days measurements in the Bulgarian Antarctic Base and includes: four trips by car, one travel by ship, four aircraft flights, one of which is crossing the magnetic equator, one travel by bus and two stays in hotels in Punta Arenas, Chile and Buenos Aires, Argentina. The lowest dose rates were measured during the trips by car. The dose rates during the ship travel were smaller than the dose rates on the ground. The dose rates registered in a bricks building in Sofia were higher than the ground dose rates. As expected, the highest dose rates were registered during the aircraft flights. The different dose rates and spectra are described and analyzed in this paper.

Keywords: Antarctic Base absorbed dose rate; Equivalent dose rate; Flux

Introduction

The Bulgarian Antarctic Base "St. Clement Ohridski" (BAB, Fig. 1) is located in the eastern part of Livingston Island, South Shetland Islands. The base was established on April 26-29, 1988. It was named after St. Clement of Ohrid, a prominent Bulgarian scholar and bishop, by a Presidential decree in 1994. The base is used by scientists from Bulgaria and other countries for research in various fields, including geology, biology, glaciology, topography, and geographic information.

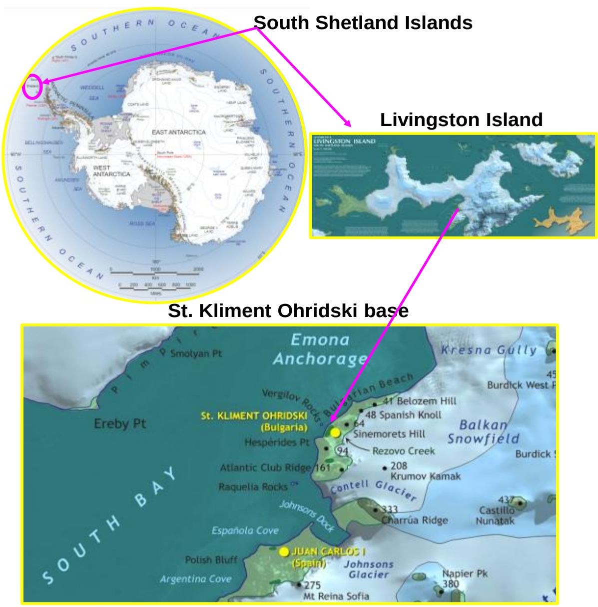

Fig. 1.Geographical position of the The Bulgarian Antarctic Base "St. Kliment Ohridski".

Liulin-AA description

The design of the portable dosimeter-spectrometer Liulin-AA is not a new one. Since 1989, Space Research and Technology Institute (SRTI-BAS), in an international cooperation with scientists from Russia, Germany, Japan, Czech Republic, Italy, Norway, Switzerland, Belgium, USA and India, etc., worked at mountain peaks, flew in space and on stratospheric balloons, rockets and aircraft with more than 35 similar devices [Dachev 2009; Dachev et al, 2015, 2017, Dachev, 2021, http://www.space.bas.bg/SollarTerrestialPhysics/files/Poster-IKIT-BAN-2019%20SZF.pdf].

The last use of Liulin device is the flight of first commercial mission into suborbital space with the SpaceShipTwo spacecraft of Virgin Galactic Company. (Virgin Galactic launches first commercial spaceflight (spacedaily.com)). The flight took place on 29th of June 2023 at 08:00 a.m. MT or 03:00 p.m. GMT from Spaceport America in New Mexico, USA. The preliminary results for the altitudinal profile obtained during the flight were published by Dachev et al, [2023].

Liulin-AA spectrometer (Fig. 2) contains one silicon-PIN diode of Hamamatsu S2744-08 type (2 cm^2 area and 0.3 mm thickness, Fig. 4), one ultra-low noise charge-sensitive preamplifier of AMPTEK A225F type (Fig. 2), and 2 microcontrollers.

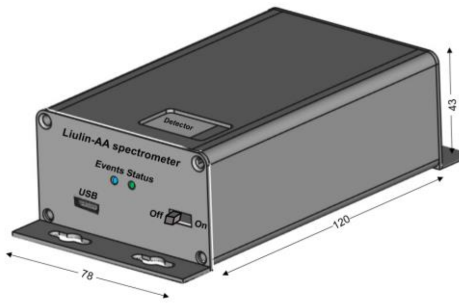

Fig. 2. Draft of Liulin-AA spectrometer.

The doses (deposited energies in the detector) are determined by a pulse height analysis technique and then passed to a discriminator. According to AMPTEK A225 specifications, the pulse amplitudes A [V] are proportional by a factor of 240 mV/MeV to the energy loss in the detector and respectively to the dose. This is the key feature of the AMPTEK A225 preamplifier, which directly transfers the pulse amplitude, measured in volts by the spectrometer to dose and dose rate.

The amplitudes of all signals from the incoming particles and quanta are transformed into digital signals by an ADC converter and are sorted into 256 channels by a multichannel analyzer. For every exposure interval, a single 256 energy deposited spectrum (EDS) is collected.

Two microcontrollers, through specially developed firmware, manage the unit. The Liulin-AA communicates with a personal computer (PC) by a universal serial bus (USB) signal.

The following method for calculations of the dose is used [Dachev et al., 2002]: The dose D [Gy] by definition is one Joule deposited in 1kg of a mater or:

$$D = K.Sum(EL_I * i)_{ET}/MD, \qquad (1)$$

where MD is the mass of the detector in [kg] and EL_i is the energy loss in Joules in channel i. Energy loss in channel i is proportional to the number of events A_i in it multiplied by i. K is a coefficient.

During the construction of the Liulin-AA instrument measures have been taken to reduce the microphone effect at the detector. As a result, it can be seen that when transporting by water, land and air under general conditions, shock and jolt disturbances are not registered anywhere. A new power supply circuit for the detector [Tomchev et al., 2023] has been constructed and used. As a result, the electromagnetic interference and noises were reduced. The device has been calibrated by applying a new methodology [Mitev et al., 2023], which leads to an increase in the accuracy and convergence of the registered data.

Experimental Results

A Preliminary Experiment to Determine the Sensitivity of Liulin-Type Instruments to Various Environmental Conditions

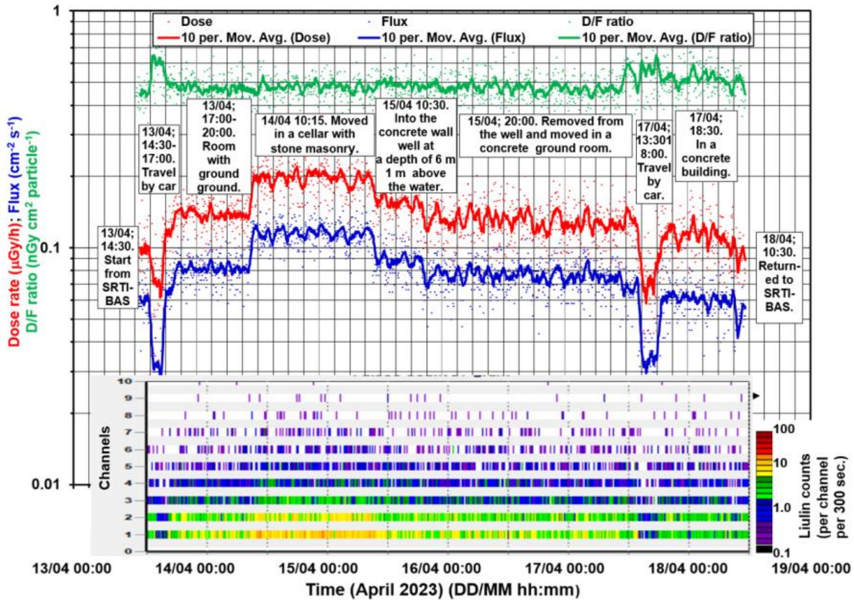

Fig. 3. Five-day battery non-stop experimental use of the Liulin-AA in different places and at different surroundings.

Fig. 3 shows five-day battery non-stop experimental measurements of the dose rate, flux and calculated dose to flux ratio by the Liulin-AA in different places and at different surroundings. The experiment began on 13th of April 2023 at 12:00 in a hut building of our institute. The instrument was initiated at 300 s exposition. The average dose rate in this position is about 0.095-μGy h^{-1}.

From 17:00 to 20:00 hours, the instrument was transported by a car from Sofia to Dimitrovgrad town in central south Bulgaria at a distance of 224 km. Due to the lack of walls and building constructions surrounding the instruments, the dose rate is the smallest observed and is about 0.07-μGy h^{-1}. Remarkable is the mean value enhancement of the dose to flux (D/F) ratio from 0.47 nGy cm^2 $particle^{-1}$ to about 6.3-nGy cm^2 $particle^{-1}$. This enhancement shows an increase of the number of counts in the higher energy deposition channels where the space radiation component is registries.

After the arrival at the destination, the instrument is placed in a house, on a floor of trampled earth for the period from 20:00 on 13th of April until 10:15 on 14th of April. The dose rate raises up to 0.135-μGy h^{-1}.

Between 10:15 on 14th of April and 10:20 on the 15th of April, the instrument is situated in a cellar with stone masonry. Here the maximal averaged dose rate is about 0.2-μGy h^{-1}. The next position of the instrument is in a well at 6 meter depth from the ground and 1 meter above the water. The walls of the well are covered by concrete cylinders. The dose rate falls down to 0.158-μGy h^{-1}. Next, the instrument is moved to a concrete ground room where the averaged dose rate is 0.13-μGy h^{-1}.

During the journey back from Dimitrovgrad to Sofia on 17 of April between 13:30 and18:10 hour the same small dose rate (0.07-μGy h^{-1}) as during the first travel is observed. Between 18:10 on 17th of April and 09:00 on 18th of April, the instrument is situated in a concrete building room where the dose rate is in average 0.115-μGy h^{-1}. After the return of the instrument in the SRTI-BAS laboratory at 09:50 on 18th of April, the same small dose rates of 0.095-mGy h^{-1} is measured as at the beginning of the experiments on 13th of April.

The conclusions from the five-day non-stop experimental use of the Liulin-AA in different circumstances and different surroundings are:

-The instrument measures stable low dose rates between 0.07 and 0.2-mGy h^{-1}. The smallest dose rate, measured during the car drive of 0.07 μGy h^{-1} is very close to the average ground base dose rate (0.073-mGy h^{-1}), measured in aircraft on the runway before the take-off [Dachev et al. 2013];

- Good repeatability of the data are seen in the two recurrent points - during the car route from and towards the SRTI-BAS of 0.095-mGy h^{-1};

The Liulin type instruments do have a good sensitivity to monitor the dose rates in different environment.

4.2. Environmental Radiation and Commercial Aviation Flights Dosimetry during a Travel from Bulgarian Antarctic Base on Livingston Island to Sofia, Bulgaria

Fig. 4 illustrates the first trip from Livingston Island to King George Island with one blue arrow. The trip by bus from Punta Arenas to Rio Gallegos is a small magenta line. All other trips, by plane, are marked with yellow arrows. The route is shown over a fragment of a map of the estimated ambient dose equivalent rate (μSv h^{-1}) at 11.887 km (FL390) [Makrantoni, et al., 2022].

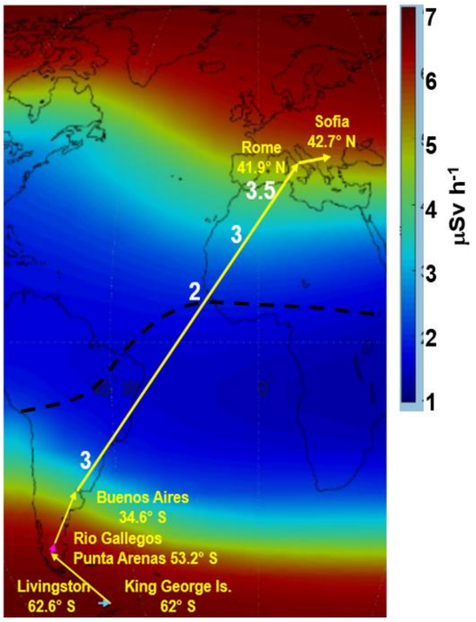

Fig. 4. The return path from Livingstone Island to Sofia, Bulgaria. It is presented over a fragment of a 3D map of the estimated ambient dose equivalent rate at 11.887 km., according to the right side color bar.

The white labels next to the flight from Buenos Aires to Rome are the measured in this points equivalent dose rates by Liulin-AA spectrometer. Good coincidence is observed.

Fig 5 contains two panels. In the upper panel

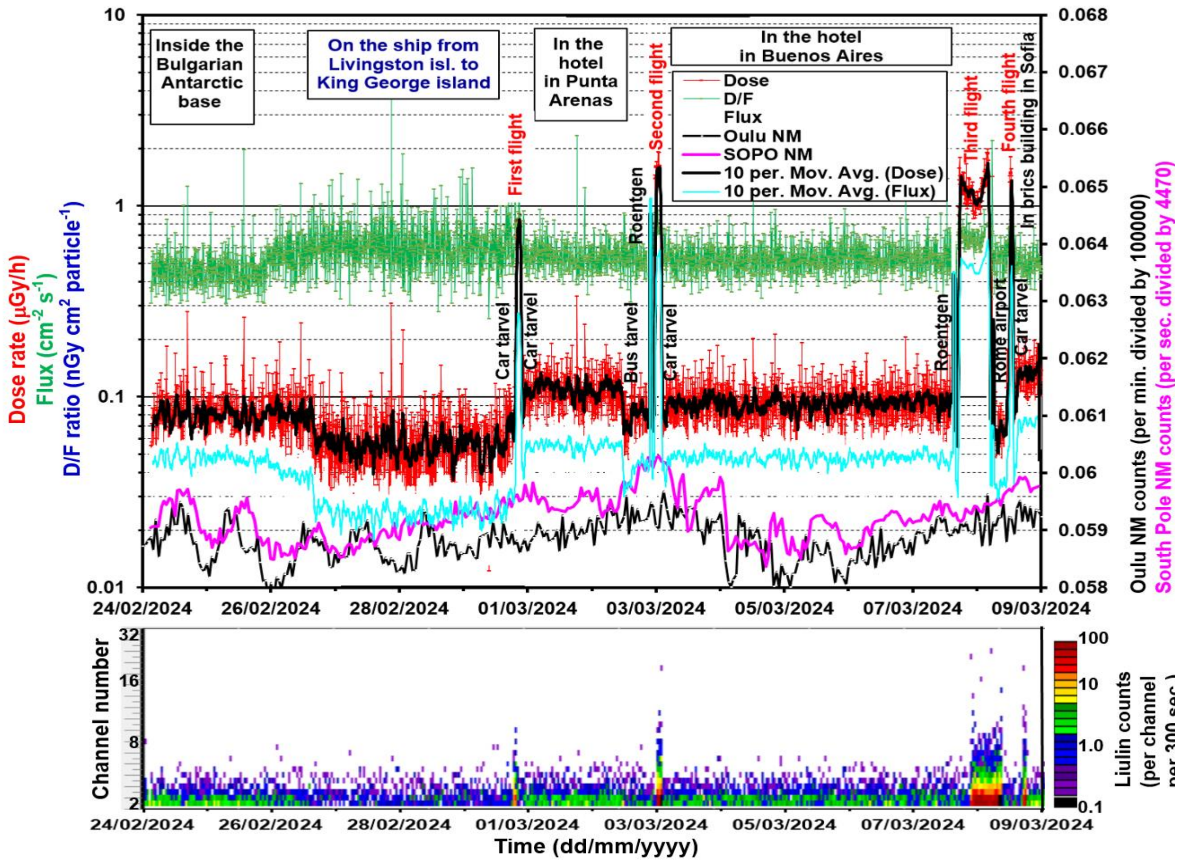

***Figure 5.** Environmental radiation and commercial aviation flights dosimetry during a travel from Bulgarian Antarctic Base on Livingston Island to Sofia, Bulgaria.*

depending from the left y-axes are plotted: a) with red line and markers the dose rate and the

10 per mowing average of dose rate with black line; b) with blue line the 10 per moving average of flux; c) the dose to flux ratio with green line and markers.

On the right y-axes of the upper panel are plotted two Neutron Monitor (NM) data: the Oulu NM https://cosmicrays.oulu.fi/ counts (per min. divided by 100000) with a black line and the South Pole NM (SOPO) https://neutronm.bartol.udel.edu/realtime/southpole.html counts divided by 4470 with a magenta line.

In the lower panel of Fig. 5 is situated a 3D color-coded graphic showing the first 32 channels’ counts in the spectra population, according to the right side color bar. No significant dependence of the dose rate from the neutron monitors values is observed.

Table 1 contains the averaged values of the absorbed dose rate, equivalent dose rate, flux, dose to flux ratio for the some points of interest of the trip back to Bulgaria.

Table 1. Comparison of the R-PM parameters, measured during experiments with Liulin type spectrometers on balloons and on SpaceShipTwo.

Location and Time	Average measured abs./ amb. eq. dose rate (μGy/h)/(μSv/h)	Average measured Flux (cm^{-2} s^{-1})	Calculated Dose to flux ratio (nGy cm^2 part.$^{-1}$)	Elevation above the see level (m)
Inside the Bulgarian Antarctic base at Livingston Island, 62.5999° S 60.4999° W, Rc=2.79 GV. **From** 24/02/2024 03:09:00 **Until** 25/02/2024 21:09:00	0.087/1.391	0,047	0.472	12-15
On the ship from Livingston island to King George island, 61.9882° S, 58.0196° W, Rc=2.84 GV. **From** 26/02/2024 16:49:00 **Until** 29/02/2024 15:49:00	0.056/0.0963	0.025	0.622	0.00
First Car travel to King George airport **From** 29/02/2024 18:04:00 **Until** 29/02/2024 18:34:00	0.0532/0.0915	0.26	0.568	
First aircraft flight from King George island to Punta Arenas, Chile, 53.1634° S, 70.9078° W, Rc= 4.54 GV. **From** 29/02/2024 19:19:00 **Until** 29/02/2024 21:14:00	0.808/1.779	0.268	0.862	9,000?
Second Car travel to Punta Arenas hotel **From** 29/02/2024 21:34:00 **Until** 29/02/2024 22:04:00	0.0757/0.130	0.041	0.519	0.516
Inside the Hotel in Punta Arenas, 53.1634° S, 70.9078° W **From** 29/02/2024 22:34:00 **Until** 01/03/2024 20:44:00	0.110/0.189	0.055	0.556	
Bus travel from the Hotel in Punta Arenas to the Airport in Rio Gallegos **From** 02/03/2024 11:09:00 **Until** 02/03/2024 18:14:00	0.078/0.134	0.0393	0.554	
First roentgen security check at Airport in Rio Gallegos **From** 02/03/2024 21:39:00 **Until** 02/03/2024 21:39:00	8.319	10.551	0.219	
Second aircraft flight from Rio Gallegos to Buenos Aires, Argentina, 34.6037° S, 58.3816° W, Rc= 8.44 GV. From 29/02/2024 19:19:00 Until 29/02/2024 21:14:00	1.543/3.696	0.561	0.766	12,000?
Third Car travel from Buenos Aires Airport to the hotel **From** 03/03/2024 05:34:00, **Until** 03/03/2024 06:14:00	0.060/0.1032	0.034	0.599	
Inside the hotel in Buenos Aires 34.6037° S, 58.3816° W **From** 03/03/2024 03:04:00 **Until** 07/03/2024 13:54:00	0.092/1.582	0.0478	0.535	25
Second roentgen security check at Buenos Aires Airport **From** 07/03/2024 15:09:00 **Until** 07/03/2024 15:09:00	3.542	4.102	0.239	
Third aircraft flight Buenos Aires to Rome, Italy, 41.8967° N, 12.4822° E, Rc= 6.2 GV. **From** 07/03/2024 17:24:00 **Until** 08/03/2024 04:09:00	1.16/3.076	0.432	0.670	12,000?
Fourth aircraft flight from Rome to Sofia, Bulgaria, 42.6977° N, 23.3219° E, Rc= 5.9 GV. **From** 08/03/2024 12:19:00 **Until** 08/03/2024 12:54:00	1.496/3.935	0.533	0.780	12,000?
Fourth Car travel from the airport in Sofia **From** 08/03/2024 13:14:00, **Until** 08/03/2024 13:34:00	0.0423/0.0727	0.0213	0.563	
Inside the bricks building in Sofia **From** 08/03/2024 14:24:00 **Until** 09/03/2024 11:09:00	0.133/0.228	0.729	0.509	

The ambient equivalent dose rates in Table 1, were calculated using the developed by [Spurny and Dachev, 2002] and later improved by [Ploc et al., 2011] method.

As seen in the first row of the Table 1, the measurements began “Inside Bulgarian Antarctic Base” on 24 February 2024 and ended on 25 February at 21:29 (Sofia time (UT+ 3 hours)) “Inside bricks building in Sofia (last row).

The measured dose rate inside the Bulgarian Antarctic Base of 0.087 μGy h^{-1} are very similar to the published by [Zanini et al., 2019] doses, obtained at the Argentine Antarctica base in Marambio (Antarctica, 64.24° S, 56.63° W, 196 m a.s.l., vertical cutoff rigidity Rc=2.35 GV). In Table 1, (therein) the measured dose rate is 75.7 ± 3.3 μGy h^{-1} in January-May 2013 and 74.6 ± 2.8 in March-October 2015.

The lowest dose rates of 0.056 μGy h^{-1} and 0.0963 μSv h^{-1} in Fig. 5 were observed during the travel on the ship between Livingston Island and King George Island. The value in μSv h^{-1} is very close to the average dose rate of 0.091 ± 0.010 μSv h^{-1} recorded by the use of a Geiger-Müller Gamma-Scoutevery during the non-stop sailing on the yacht Katharsis II from Cape Town, South Africa to Hobart, Australia around the Antarctic continent between 23 December 2017 and 5th April 2018 [Długosz-Lisiecka, 2021]. The car travel and the bus travel doses, similarly to the measured during Preliminary experiment (Fig. 3), are at low levels between 0.0423 μGy h^{-1} during the car trip between Sofia airport and Sofia town and 0.078 μGy h^{-1} during the bus trip between the hotel in Punta Arenas to the Airport in Rio Gallegos town.

The doses in different buildings during the trip varies between 0.133 μGy h^{-1} inside the brick building in Sofia and 0.092 μGy h^{-1} inside the hotel in Punta Arenas. These high doses are understandable because according to [Shahbazi-Gahrouei et al., 2013, Table 1 therein] the radioactivity concentration in (Bq/kg) in brick is the highest with 37±1.5 from ^{226}Ra, 12.2±0.7 from ^{232}Th and 851.4±15 from ^{40}K. The cement, which is the major contributor in the concrete, is on the second place.

The highest dose rates were observed during the four commercial aircraft flights, depicted on Fig. 6. The maps with the ground projection of the aircraft paths (red lines) are visible in the background of the four figures. In addition, the variations of the ambient equivalent dose rate in μSv h^{-1} (blue lines), the absorbed dose rate in μGy h^{-1} (black lines) and the dose to flux ratio in nGy cm^2 particle^{-1} (magenta lines) are also shown.

The variations of the mentioned above two dose rate parameters during first flight from King George Island (61.9882° S, 58.0196° W, Vertical cut-off rigidity (Rc) is 2.84 GV) to Punta Arenas town in Chile, (1,241 km distance) are seen in Fig. 6a. The measured absorbed and equivalent dose rate during this flight are the smallest in comparison with the other three flights. The reason is that this flight was performed with aircraft type BAe146, which cruise altitude is at about 9 km. The highest average dose to flux value of 0.862 nGy cm^2 particle^{-1} in comparison with other three flights gives information that in the spectra exist particles depositing energy in higher energy channels. This is expected due to the relative high latitudes of the flight.

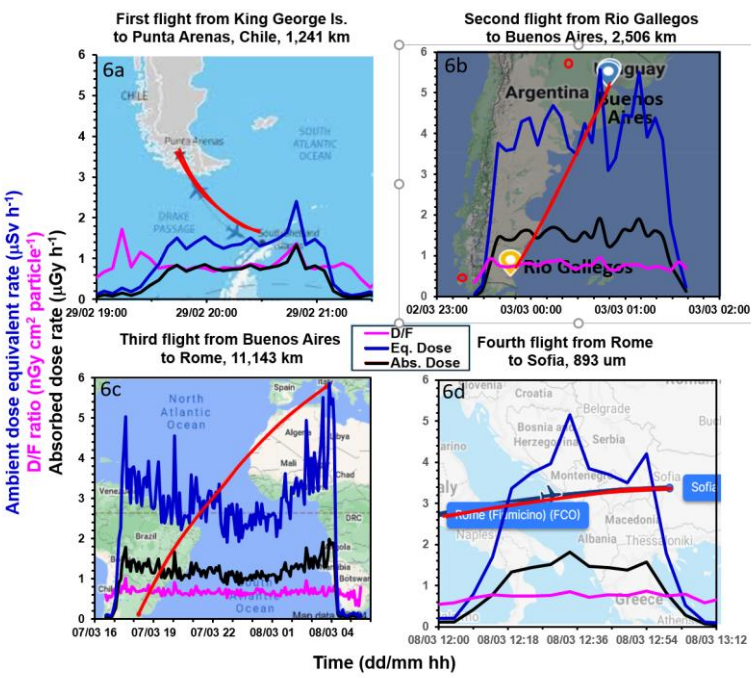

Figure 6. *Environmental radiation and commercial aviation flights dosimetry during a travel from Bulgarian Antarctic Base on Livingston Island to Sofia, Bulgaria.*

The high dose rates seen in the second and fourth flights are very similar because of the similar latitudinal (please look Fig. 4) and altitudinal conditions. This is also expected because the cruise altitude of flights 2-4 is around 12 km.

The most interesting, is the third flight being the longest and crossings the geomagnetic equator (please look at the dashed black line, Fig. 4) somewhere on the west coast of Africa. Both sides of the path in both hemispheres are from -35° to 42° geographic latitudes and Rc=6.2 GV and Rc=5.9 GV. Close after the take-off from the Buenos Aires airport and before the landing in Rome, the predicted ambient dose equivalent [Makrantoni, et al., 2022] is about 4-6 μSv h^{-1}. The latter is in a good coincidence with the values in the blue line (Fig. 6). With the decrease of the latitude toward the magnetic equator (black dashed line, Fig. 4), the doses also decrease down to values of 2-2.5 μSv h^{-1}.

Conclusions

The most important achievement of the paper is the discovery and the proof of the existence of stable measurements of Liulin type instruments in different ground and aircraft circumstances and different natural radiation surroundings.

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