DOI: 10.31401/WS.2025.proc.17

Space Radiation Measurements during a Ship Round Trip from Varna, Bulgaria to Bulgarian Antarctic Base on Livingston Island

Dachev T.P.[1], Sapundjiev P.V.[2], Tomov B.T.[1], Matviichuk Y.N.[1], Mitev M.M.[1], Jordanova M.[1]

[1]Space Research and Technology Institute, Bulgarian Academy of Sciences, Sofia, Bulgaria
[2]National Institute of Geophysics, Geodesy and Geography, Bulgarian Academy of Sciences, Sofia, Bulgaria

Abstract

The spectrometer-dosimeter Liulin-AA performed radiation measurements during a round trip on board of the Bulgarian scientific research ship "St. St. Cyril and Methodius" from Varna, Bulgaria, to the Bulgarian Antarctic Base on Livingston Island. Different radiation and environment conditions were identified. The trip started with few days measurements in the Black Sea with an average dose rates of 0.0562-μGy h^{-1}, continued with recording of descending dose rates towards the magnetic equator while crossings in Atlantic Ocean and ended at the Bulgarian Antarctic Base on Livingston Island. Close to the magnetic equator on the back trip, the averaged dose is 0.0494-μGy h^{-1}. This is the smallest dose observed by Liulin-AA during the registrations performed in the Arctic and Antarctic regions in 2024 and 2025. The average detected doses on Livingston Island were considerably higher and reached 0.0806-μGy h^{-1}. They were measured during monitoring inside the Bulgarian base from 1st till 14th of February, 2025. The radiation doses measured on the way back from Livingstone Island to Varna were similar to those, already observed, during the first half of the round trip.

Keywords: Space radiation measurements; Liulin spectrometer-dosimeter

1. Introduction

Cosmic rays at sea level consist mostly of neutrons, protons, peons, muons, electrons, and photons. The particles, which cause significant soft fails in electronics, are those particles with the strong interaction: neutrons, protons, and peons. At sea level, about 95% of these particles are neutrons.

The level of exposure to cosmic radiation also increases with altitude since there is less air as altitude increases to act as a shield. Consequently, someone living at sea level will, on average, receive a lesser dose of cosmic radiation every year than an individual living in locations above 2,000 meters.

The earth's magnetic field is the main reason for the decrease in cosmic ray intensity at the equator. In the poles, the charged particles are travelling parallel to the direction of the magnetic field. Thus, they can travel to earth almost unhindered so the intensity is always maximum at the poles.

There were two expeditions with the Liulin-AA spectrometer in 2024. The First expedition was from Livingstone Island to Sofia, Bulgaria [Dachev et. al., 2024a]. The Second one from Sofia, Bulgaria to Longyearbyen town, Norway and back [Dachev et. al., 2024b].

This paper presents the analysis of the data obtained in 2025 during the third expedition with Liulin-AA. This is a round trip by ship from Varna, Bulgaria to Bulgarian Antarctic Base on Livingston Island.

2. 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 remarkable use of Liulin device in space are: the measurements outside the Japanese experimental module of International Space Station in September-October 2022 and the space radiation data during the first-ever commercial mission into suborbital space with the SpaceShipTwo spacecraft of Virgin Galactic Company (Virgin Galactic launches first commercial spaceflight (spacedaily.com)). This 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, [2024c].

Liulin-AA spectrometer (Fig. 1) contains one silicon-PIN diode of Hamamatsu S2744-08 type (2 cm^2 area and 0.3 mm thickness), one ultra-low noise charge-sensitive preamplifier of AMPTEK A225F type and 2 microcontrollers.

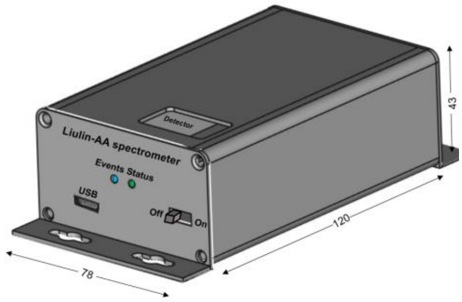

Figure 1. *Draft of Liulin-AA spectrometer.*

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.

3. Experimental Results

Figure 2. *"St. St. Cyril and Methodius" ship, performed the round trip from Varna to the Bulgarian Antarctic Base.*

The Bulgarian naval research vessel "St. Cyril and Methodius" (Fig. 2.) set sail on November 7, 2024 from Varna Marine Station on its third polar expedition to Antarctica. The crew consists of 34 people. Radko Muevski is the captain. It reached the Bulgarian Antarctic base on December 30, 2025, stay there for 45 days, set sail for the return voyage on February 15, 2025, and arrive back in Varna on 11 April 2025.

3.1.Results from the trip from Varna, Bulgaria to Bulgarian Antarctic Base on Livingston Island

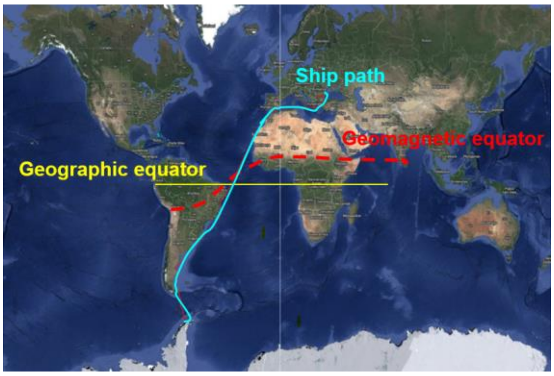

Figure 3. *Geographic map of the experiment.*

Fig. 3 presents the geographic map of the experiment. Three curves illustrate: (1) the ship path (magenta line) as monitored by the GPS receiver. The return path is not presented, as it was almost the same as the first route. (2) The geographic equator is shown with yellow line, while the (3) geomagnetic equator with a red line. It is seen that the ship first crosses the geomagnetic equator and next the geographic one.

Fig. 4 presents the results obtained during the trip from Varna to Antarctica in two panels.

The upper panel (4a) presents the measured dose rate between 24 October 10:30 UT and 30 December 11:45 UT, while the lower panel illustrates the geographic latitude of the ship, obtained by the GPS logger next to the Liulin-AA instrument. The dose rates measured by 5-minute resolution are marked with black points, while the daily averaged dose rates with red points, connected with a heavy black line. The average dose rate at the surface of the Atlantic Ocean is 0.05 μGy h^{-1}, which is 22 times less (1.1 μGy h^{-1}) than at 12 km altitude during aircraft flight.

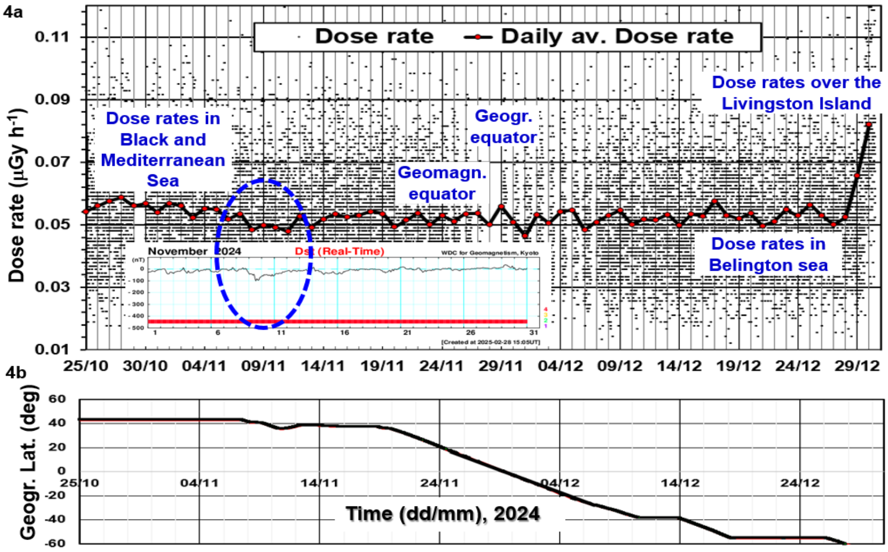

Figure 4. *Measured dose rates during the trip from Varna to Livingston Island.*

During the first part of the trip, close to 40° Northern latitude, inside Black and Mediterranean seas is observed tendency for higher dose rates. Similar tendency is seen in Belington Sea before the Livingstone Island. On the back trip, the higher doses inside the Black and Mediterranean seas is observed again. The explanation of this effect is the smaller depth, allowing Gamma radiation from the bottom to penetrate up to the sea level.

The dose rates drastically increase when the Liulin-AA instrument reaches the shore of the Livingston Island. Similar effects are observed on the back trip over the Livingston and Varna shores. The increase is explained with the absence of the shielding by the seawater. The natural Gamma radiation from the shore rocks and Radon component from the air and cosmic radiation are detected by the Liulin-AA instrument and increase the radiation level up to about 0.1 µGy h^{-1}, which is the level of the natural radiation.

The Forbush effect (Forbush, 1937) from a small magnetic storm on 9th of November 2024 decreases the dose rates. It is shown that the decrease of the dose rate, centered on 9th of November, coincides with the Disturbance Storm-Time Indices (Dst) index (Maus, and Weidelt, 2004) decrease registered on the Dst indices graphic for November 2024 (https://wdc.kugi.kyoto-u.ac.jp/dst_realtime/202411/index.html).

Results from the trip from Bulgarian Antarctic Base on Livingston Island to Varna, Bulgaria

Fig. 5, in a similar way as Fig. 4, presents the measured dose rates on the way back from Bulgarian Antarctic base on Livingston Island to Varna. Close to the magnetic equator, the averaged dose is 0.0494-µGy h^{-1}. This is the smallest dose observed by Liulin-AA during the registrations performed in the Arctic and Antarctic regions in 2024 and 2025.

3.2. Dose rate variations during a snowmobile trip on 1st of February 2025 and continues monitoring inside the Bulgarian base between 1st and 14th of February 2025

Fig 6. Presents the results of the measured spectra and dose rates during a snowmobile trip on the morning of 1st of February 2025 and the continues monitoring inside the Bulgarian base between 1st and 14th of February 2025.

Fig. 6a contains the energy-time (ET) graph showing vertically situated the color-coded 300-second spectra from 1st to 128th channels. The major amount of counts is produced by gamma rays in low energy deposited in the first five channels. The single counts up to 112th channels are produced by galactic cosmic rays primary and secondary particles as protons and muons.

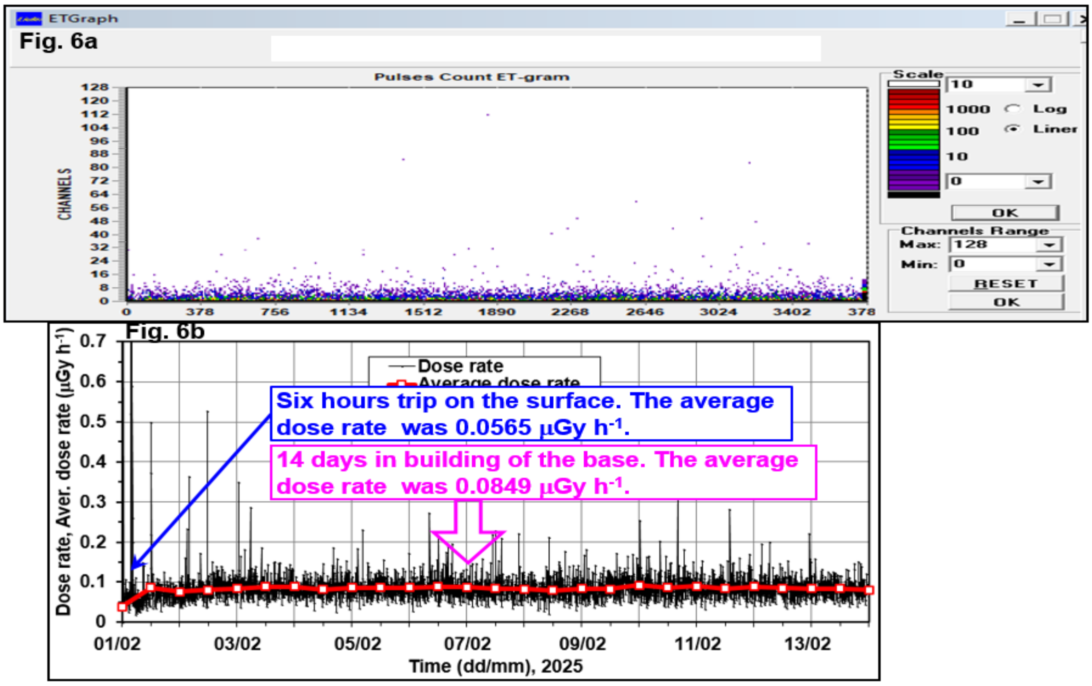

Figure 6*. Results of the measured spectra and dose rates between first and fourteenth of February 2025.*

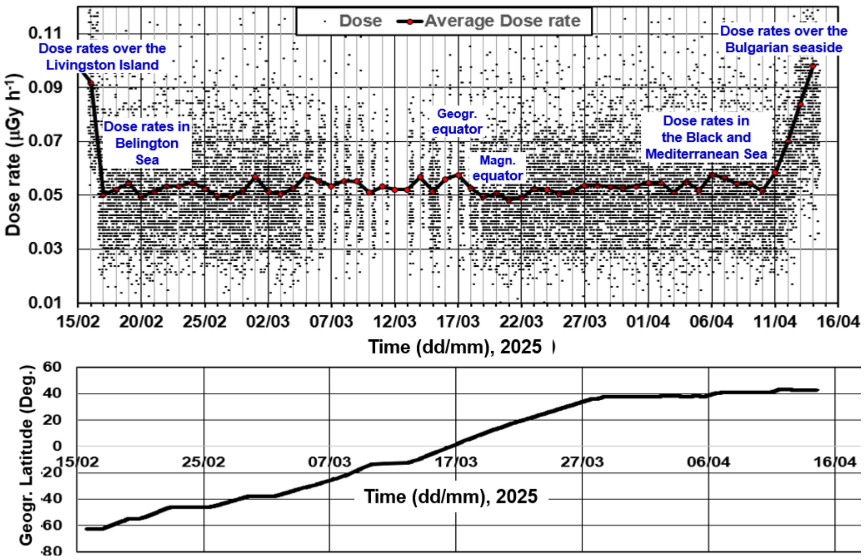

Figure 5. *Measured dose rates during the trip from Livingston Iceland to Varna.*

Fig 6b shows the variations of the measure dose rate. Because of the smaller amount of gamma rays on the open air, the average dose rate during the 6-hour snowmobile trip on the 1st of February 2025 is 0.0565-μGy h^{-1}. The average dose rate inside the building of the Antarctic base is 0.0849-μGy h^{-1}.

Conclusions

Liulin-AA measurements on ship during the round trip from Varna to Antarctica of 0.0527 μGy h^{-1} and back of 0.0528 mGy h-1 coincide with our measurements in 2024 of 0.0565 μGy h^{-1} (Dachev T. P., Sapundjiev et. al. (2024a). They are also in good correspondence the measurements performed in the Antarctic region at the surface of the sea with a portable Gamma Scout Online radiometer. The latter obtained an average dose rate of 0.0548 μGy h^{-1} (Długosz-Lisiecka et al. 2019, https://doi.org/10.18778/1427-9711.20.01).

During the six hours trip on the surface of Livingstone Island with a snowmobile the average dose rate was 0.0565 μGy h^{-1}. This small dose rate value is similar with the observed during all trips with car and bus in 2024 and 2025.

The measured average dose rate for 14 days inside the building of the Bulgarian base of 0.0849 μGy h-1 well coincides with value of 0.087, measured in February 2024 and with the measurements inside the Argentine Antarctica base in Marambio of 0.080 μGy h^{-1} with Liulin-I MDU-1 LET Spectrometer (Zanini et al. 2017, http://dx.doi.org/10.1016/j.jenvrad.2017.04.011).

As expected the Forbush effect from the small magnetic storm on 9 November 2024 decreases almost twice the dose rates.

Acknowledgements

The authors thank to all Bulgarian and foreign specialists and organizations that participated in the development of Liulin instruments.

Peter Sapundjiev is very thankful to Project/Contract No 70-25-94 from 28.04.2023, supported by National Program for Polar Studies "From Pole to Pole" 2022 – 2025.

IKIT-Antarkticheski Scientists from Bulgarian Academy of Sciences

The space radiation measurements during the round trip by from Varna, Bulgaria to Bulgarian Antarctic Base on Livingston Island was performed as part of the Memorandum of Understanding between Space Research and Technology Institute, Bulgarian Academy fo Sciences and the Bulgarian Antarctic Institute from 2024.

References

Dachev, T.P., Sapundjiev, et al. (2024a). Dose rate and flux measurements during a travel from Bulgarian Antarctic Base on Livingston Island to Sofia, Bulgaria, *Proceedings of the Seventeenth Workshop “Solar Influences on the Magnetosphere, Ionosphere and Atmosphere”*, Primorsko, Bulgaria, June, pp. 75–83, 2024. Available at: https://www.spaceclimate.bas.bg/ws-sozopol/pdf/Proceedings2024.pdf

Dachev, T.P., Sapundjiev, et al. (2024b). LIULIN-AA spectrometer measurements of the radiation dose during the travel from Bulgarian Antarctic Base on Livingston Island to Longyearbyen town, Svalbard Archipelago, Norway and back to Sofia, *Proceedings of the Seventeenth International Scientific Conference “Space, Ecology, Safety” – SES 2024*, Sofia, Bulgaria, 22–25 October 2024, pp. 33–42.

Dachev, T.P., Carlucci, et al. (2025). Space radiation measured during first-ever commercial suborbital mission on Virgin Galactic SpaceShipTwo Unity on 29 June 2023, *Life Sciences in Space Research*, Vol. 44, pp. 126–133, DOI: 10.1016/j.lssr.2024.09.003.

Forbush, S.E. (1937). On the effects in cosmic-ray intensity observed during the recent magnetic storm, *Physical Review*, Vol. 51, No. 12, p. 1108, DOI: 10.1103/PhysRev.51.1108.3.

Maus, S., Weidelt, P. (2004). Separating the magnetospheric disturbance magnetic field into external and transient internal contributions using a 1D conductivity model of the Earth, *Geophysical Research Letters*, Vol. 31, No. 12, DOI: 10.1029/2004GL020232.

Mitev, M., Tsankov, L., et al. (2023). Radiationless energy calibration of radiation survey meters, *Proceedings of the XXXII International Scientific Conference "Electronics (ET)"*, Sozopol, Bulgaria, 2023, pp. 1–4, DOI: 10.1109/ET59121.2023.10279419.

Tobiska, K., Dachev, T., et al. (2024a). Radiation field outside the ISS observed by ARMAS Flight Module 9, March–December 2022, *Proceedings of the Twenty-Seventh WRMISS Workshop*, Boulder, CO, USA, 3–5 September 2024. Available at: https://wrmiss.org/workshops/twentyseventh/Tobiska.pdf

Tobiska, K., Dachev, et al. (2024b). International Space Station radiation field measurements by Liulin-SET spectrometer of ARMAS Flight Module 9 in 2022, *Proceedings of the Twentieth International Scientific Conference "Space, Ecology, Safety" – SES 2024*, Sofia, Bulgaria, 22–25 October 2024, pp. 16–22. Available at: http://www.space.bas.bg/SES/archive/SES%202024_DOKLADI/Plenary%20Session/2_Dachev.pdf

Tomchev, N., Mitev, et al. (2023). Novel linear step-up power supply module for detector systems, *Proceedings of the 32nd International Scientific Conference "Electronics (ET)"*, Institute of Electrical and Electronics Engineers Inc., ISBN: 979-835030200-4, DOI: 10.1109/ET59121.2023.10279817.