PRELIMINARY SPACE RADIATION RESULTS FOR THE FIRST-EVER COMMERCIAL SUBORBITAL MISSION GALACTIC 1 WITH VIRGIN GALACTIC SPACESHIPTWO UNITY ON 29 JUNE 2023

Tsvetan Dachev[1], Pantaleone Carlucci[2], Francesco Cairo[2], LuciaPaciucci[3], Borislav Tomov[1], Yuriy Matviichuk[1], Plamen Dimitrov[1], Mityo Mitev[1], Malina Jordanova[1]

[1]Space Research and Technology Institute - Bulgarian Academy of Sciences (SRTI-BAS), Sofia, Bulgaria,
E-mail: tdachev59@gmail.com
[2]National Research Council of Italy, Institute of Atmospheric Sciences and Climate (CNR-ISAC), Rome, Italy,
E-mail: francesco.cairo@artov.isac.cnr.it
[3]National Research Council of Italy, Engineering, ICT and Technologies for Energy and Transportation Department (CNR-DIITET), Rome, Italy
E-mail: lucia.paciucci@cnr.it

Keywords: *Space Radiation Dose and Dosimeters, Dose Rate Profile*

Abstract: *The paper presents the Portable Dosimeter-Spectrometer (PDS) Liulin-CNR-VG, measuring the space radiation altitudinal profile during the flight of the Virgin Galactic SpaceShipTwo Unity on 29 June 2023 (https://www.space.com/virgin-galactic-first-commercial-mission-success). The PDS size is 66x56x26 mm. Its weight is 0.092 kg. The PDS measures the following parameters: the flux of the charged particles in the range from 0.1 to 20,000 particles per square centimeter in 1 second; the absorbed dose in the range from 0.3 nGy to 1.56 mGy; the dose rate in the range from 0.04 to 0.18 mGy h^{-1}. The altitude profile during the mission of Virgin Galactic SpaceShipTwo Unity up to the 37.2 km altitude is similar to the profiles measured on aircraft up to 12 km altitude and on unshielded Liulin battery operated unit during the June 8, 2005 certification flight of the NASA Deep Space Test Bed balloon flight launched from Ft. Sumner, New Mexico, USA.*

During the first part of the SpaceShipTwo flight, up to 13.7 km, the dose rate rises from 0.058- mGy h^{-1} up to 2.5 mGy h^{-1}. The Pfotzer maximum is not well observed in the ascending part of the flight, because of the relative small statistics for the chosen exposition of 10 sec and fast movement of the vehicle on the ascending part of the trajectory. Above the Photzer maximum, at about 85 km altitude, the dose falls down to 2.2 μGy h^{-1}. The equivalent dose during the flight of is calculated to be about 5.18 μSv for 2.37 hours. This reveals that there is no radiation risk for the pilots and astronauts flying at the Virgin Galactic (VG) SpaceShipTwo up to 85.1 km altitude.

ПРЕДВАРИТЕЛНИ ДАННИ ЗА МОЩНОСТИТЕ НА ДОЗИТЕ ПРИ ПЪРВАТА КОМЕРСИАЛНА, СУБОРБИТАЛНА МИСИЯ „ГАЛАКТИК 01“ С КОСМИЧЕСКИЯ КОРАБ “СПЕЙСШИП 2“ НА ФИРМАТА „ВЪРДЖИН ГАЛАКТИК“

Цветан Дачев[1], Pantaleone Carlucci[2], Francesco Cairo[2], Lucia Paciucci[3], Борислав Томов[1], Юрий Матвийчук[1], Пламен Димитров[1], Митьо Митев[1], Малина Йорданова[1]

[1]Институт за космически изследвания и технологии – Българска академия на науките,
E-mail: tdachev59@gmail.com
[2]Национален съвет за научни изследвания на Италия, Институт за атмосферни науки и климат, Рим, Италия, E-mail: pantaleone.carlucci@cnr.it, francesco.cairo@artov.isac.cnr.it
[3]Национален съвет за научни изследвания на Италия, отдел „Инженеринг, ИКТ и технологии за енергетика и транспорт“, Рим, Италия, E-mail: lucia.paciucci@cnr.it

Ключови думи: *Доза и дозиметри за космическа радиация, Профил на мощността на дозата*

Резюме: *Докладът представя дизайна на преносимия дозиметър-спектрометър (PDS) Liulin-CNR-VG, който измери височинния профил на космическата радиация по време на полета на космическия кораб “Спейсшип 2“ на фирмата „Върджин Галактик“ на 29 юни 2023 г.*

(https://www.space.com/virgin-galactic-first-commercial-mission-success). Размерът на преносимия дозиметър-спектрометър е 66x56x26 mm, а теглото - 0,092 kg. Приборът измерва следните параметри: потока на заредените частици в диапазона от 0,1 до 20 000 частици на квадратен сантиметър за 1 секунда; погълнатата доза в диапазона от 0,3 nGy до 1,56 mGy; мощността на дозата в диапазона от 0,04 до 0,18 mGy h^{-1}. Височинният профил по време на мисията на Спейсшип 2" до 37,2 km надморска височина е подобен на профила, измерен на самолет до 12 km надморска височина, както и на профила от преносимия дозиметър-спектрометър Liulin, работещ с батерии, без екраниране, по време на сертификационния полет с балон на NASA Deep Space Test, изстрелян от Ft. Sumner, Ню Мексико, САЩ на 8 юни 2005 г.

През първата част от полета на "Спейсшип 2", до 13,7 km, мощността на дозата нараства от 0,058- mGy h-1 до 2,5 mGy h^{-1}. Максимумът на Pfotzer не се наблюдава добре във възходящата част на полета, поради относително малка статистика за избраната експозиция от 10 секунди и бързото движение на Спейсшип -2 във възходящата част на траекторията. Над максимума на Пфотцер, на около 85 km височина, дозата пада до 2,2 μGy h-1. Еквивалентната доза по време на полета е изчислена на 5,18 μSv за 2,37 часа. Това разкрива, че няма радиационен риск за пилотите и пътниците - космически туристи, летящи с „Върджин Галактик Спейсшип 2" до 85,1 km височина.

Introduction

The era of suborbital touristic flights up to 110 km altitude is already open by the missions of Virgin Galactic first crewed spaceflights on 11 July 2021 with Richard Branson on board and Blue Origin on July 20 2021 with Jeff Bezos on board. It is rather difficult to say exactly where the atmosphere ends and space starts. A widely accepted definition uses what is called the Karman line (*https://astronomy.com/news/2021/03/the-krmn-line-where-does-space-begin*), which is at 100 km above the sea level (ASL) as the boundary for space. According to NASA and the U.S. military, space starts at 80 km ASL. Richard Branson and his crew in the Virgin Galactic SpaceShip Unity flew to an altitude of 86 km, whereas Jeff Bezos and other passengers in Blue Origin rocket flew up to 107 km.

Virgin Galactic has conducted its first commercial mission into suborbital space with the SpaceShipTwo spacecraft. (Virgin Galactic launches first commercial spaceflight (spacedaily.com)) The flight began on June 29, 2023 at 08:00 a.m. MT or 03:00 p.m. GMT from Spaceport America in New Mexico, USA (https://www.virgingalactic.com/). Virgin Galactic calls this mission Galactic 01. It is a joint research study of the Italian Air Force and the National Research Council of Italy called "VIRTUTE 1" (**V**olo **I**taliano per la **R**icerca e la **T**ecnologia s**U**borbi**T**al**E**- Italian Flight For Sub-Orbital Research and Technology) (Please look Fig. 1. a.) The mission lasted about 90 minutes, reaching an altitude of 85.1 kilometers.

Fig. 1.a Fig. 1.b Fig. 1.c

Fig. 1.a SpaceShipTwo and the logo of VIRTUTE 1 mission;
Fig. 1.b The VIRTUTE 1 mission crew;
Fig. 1. c. External view of the Liulin-CNR-VG instrument and the managing computer.

The VIRTUTE 1 mission crew was Pantaleone Carlucci, an engineer at Italy's National Research Council, Colonel Walter Villadei of the Italian Air Force, Lt. Col. Angelo Landolfi, an Italian Air Force physician and Colin Bennett, an astronaut instructor at Virgin Galactic (Fig. 1. b, names listed from left to right).

The VIRTUTE 1 mission includes 13 experiments, (https://www.virgingalactic.com/galactic-01-research-payloads-fact-sheet) as follows: 1. Liulin-CNR-VG; 2. Doosy-CNR-VG; 3. droP Impact in micro-Gravity (PING); 4. Italian Combustion Experiment – Suborbital Flight (ICE – SF); 5. TetRafluoroethAne sponge (TRAP); 6. Cabin Air Quality (CAQ); 7. SHApe Recovery of Composite Structures; 8. (SUNRISE-VG01-SHARCS) TESting in Space (SUNRISE-VG02-TESIS); 9. Scientific-

Health Area Experiments; 10. Smart Flight Suit 1 (SFS1); 11. ECG Holter Monitoring; 12. Passenger well-being; 13. Pre- and post-flight ground activities.

The Portable Dosimeter-Spectrometer Liulin-CNR-VG (Please look Fig. 1.c) is an object of a Bulgarian - Italian research project "Portable Dosimeter- Spectrometer Liulin-CNR-VG". The project partners are Space Research and Technology Institute of the Bulgarian Academy of Sciences (SRTI-BAS) and National Research Council of Italy (CNR).

The design of the portable dosimeter-spectrometer Liulin-CNR-VG is not a new one. Since 1989, SRTI-BAS, in international cooperation with scientists from Russia, Germany, Japan, Czech Republic, Italy, Norway, USA and India flew in space with seventeen similar devices [1-2].

Instrument description

The external view of the portable dosimeter-spectrometer (PDS) is presented on Fig. 1.c. It is situated in an Extruded Aluminum Enclosure with a size 66x56x26 mm. The weight of the PDS is 0.098 kg.

The Portable dosimeter-spectrometer Liulin-CNR-VG measures the following parameters: the flux of the charged particles with an ionizing capacity above 1 MeV/mm in silicon, with a sensitive area of 2 cm^2, an energy resolution of 100 keV in the range from 0.1 to 20000 particles or quanta per square cm per sec.; absorbed dose in the range from 0.3 nGy to 1.56 mGy; dose rate in the range from 0.04 μGy h^{-1} to 0.18 Gy $^{-1}$, energy deposited in the detector from 0.08 to 20.3 MeV. The measurement error is no more than ± 20%.

The Liulin-CNR-VG PDS is a Liulin type deposited energy spectrometer (DES) [1]. It uses one silicon detector to measure the deposited energy and the number of particles or quanta that allows calculating the dose rate and the flux.

The spectrometer-dosimeter contains one silicon-PIN diode of Hamamatsu S2744-08 (2 square cm area and 0.3 mm thickness), 1 ultra-low noise charge-sensitive preamplifier of AMPTEK A225F, 2 microcontrollers and 64 MB flash memory.

On the upper panel of the PDS are mounted the ON/OFF switch, the green status LED and the USB mini female connector. Below the panel are situated two rechargeable cylindrical AAA size Lithium-Ion cells 10440 of Portable Power Corp.

Above the 0.5 mm thick bottom panel of the PDS is situated the 2 cm^2 Hamamatsu PIN diode detector. In addition, there is a technological shielding of 0.07-mm copper and 0.2-mm plastic material. They all provide a total shielding of 0.25 g cm^{-2}. The calculated required kinetic energies of normally falling particles to the detector are 0.67 and 12.5 MeV for electrons and protons, respectively (https://www.nist.gov/pml/stopping-power-range-tables-electrons-protons-and-helium-ions). This indicates that only protons and electrons with energies higher than the values listed above can cross the PDS shielding materials and reach the surface of the detector.

After passing a charge-sensitive preamplifier, the signal is digitized by a 12-bit fast analog to digital (A/D) converter. The doses (deposited energies) are determined by a pulse height analysis technique and then passed to a discriminator.

According to AMPTEK A225F 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. The amplitude of each signal from the income particles and quanta are transformed into digital signals, which are sorted into 256 channels by a multichannel analyzer. For every exposure interval, a single 256 channels energy deposition spectrum is collected. The energy channel number 256 accumulates all pulses with amplitudes exceeding the maximal level of the spectrometer of 20.83 MeV.

A system international (SI) determination of the dose is used to calculate the absorbed dose in the silicon detector. The dose in SI is the energy in Joules deposited in one kilogram of a matter. The dose *D* (in Gy) in the silicon detector is calculated from the spectrum as:

$$D=K*\Sigma_1^{256}(Ei*Ai)/MD, \quad (1)$$

Where *MD* is the mass of the detector (in kg), *Ei* is the energy loss (in Joules) in the channel *i, Ai* is the number of events in it, and *K* is a coefficient. Dachev et al. [2] published recently the dose calculation procedure in details.

Experimental results

Figure 2 shows the dynamics of the dose rate, measured with the spectrometer Liulin-CNR-VG during the Galactic 01 mission. As this dynamic is mainly because the variations of the SpaceShip Two altitude, the altitude, as provided by Virgin Galactic, is plotted with green line. Except the altitude, the calculated dose to flux ratio is presented with a blue line. The black line is for Total Dose in μGy.

In the first part of the figure between 08:00 and 08:34 MT (Mountain Time), the space plane is on the ground, i.e. the measurements were performed in the natural background radiation environment with a minimal measured dose rate of 0.00 μGy h^{-1} and a maximal dose rate of 0.6042 μGy h^{-1}. The main contribution in the dose are coming from in soil gamma radiation sources. emitting gamma quanta.

The relative large dispersion in the measured values well seen in right part of Fig. 2 is result of the small exposition time of 10 s, which allowed accumulation of maximum 4 particles or quanta per 10 s exposition. This statistics is not enough to calculate more precisely the dose rate. The average dose rate value between 08:00 and 08:34 MT is 0.1036 μGy h^{-1}, which is larger than the world average natural background radiation dose rate of 0.0585 μGy h−1 with a minimum dose rate of 0.018 and maximum of 0.095 μGy h^{-1} [3, 4]. Additional doses are coming from the galactic cosmic rays (GCR), which amount increases with the altitude above the sea level (ASL). Spaceport America is at almost 1.4 km ASL.

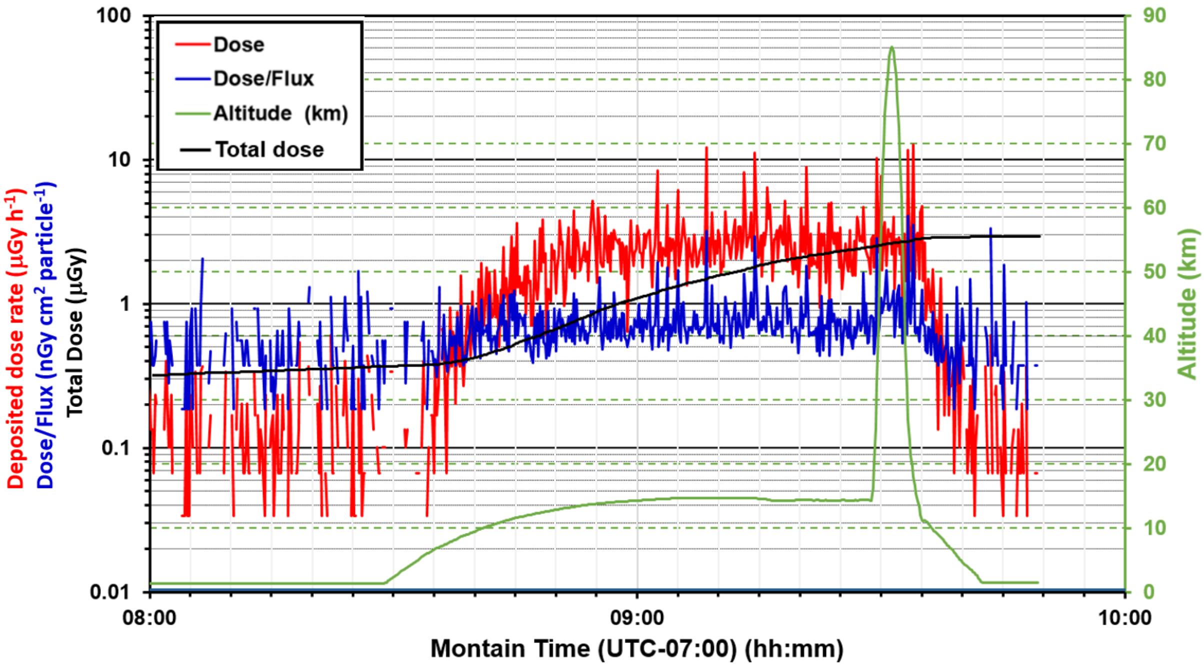

Fig. 2. Shows with red line the 10 s data for the dose rate, measured by Liulin-CNR-VG and the calculated ratio of dose rate to flux with a blue line. The green line presents the altitude in km, while the black line – the total accumulated dose in μGy.

After the take-off, the plane starts to climb up and at 09:00 MT reaches an altitude of 14.3 km. During this movement, the dose rate rises up to 2.45 μGy h^{-1}. Further, between 09:00 MT and 09:25 MT the plane stays at almost fixed altitude of about 14.47 km. The average dose rate is also fixed at 2.86 μGy h^{-1}. The Dose to Flux ratio at the fixed altitude also rises up to 0.76-nGy cm^2 $particle^{-1}$.

The strong maxima seen in the dose rate (red line) between 09:00 MT and 09:35 MT are always connected with maxima in the Dose/Flux ratio (blue line). The more precise look in the spectra shows that the reason for the large doses and large Dose/Flux values is the presence in the spectrum of events in channels number above 150. The high-energy depositions in the spectrum are at high channel numbers. For example, the highest dose rate of 12.79 μGy h^{-1}, observed at 09:34:00 MT is connected with an energy deposition in 256^{th} channel of the spectrometer.

High-energy depositions manifested also the existence of another radiation source. This source are the low energy protons existing in the Photzer maximum [5] at altitudes close to 20 km. Crossings of the Photzer maximum produced the five dose rate maxima at both side of the altitudinal maximum at 85.1 km. In each of these maxima high-energy deposition from protons are seen in the channels above 150.

The small statistic of about 19 events in the spectra around the ascending Photzer maximum position of 20 km is the reason for not well-seen dose rate increase. The expected decrease of the dose rate above the Photzer maximum [6] is also not well seen in Fig. 2.

On the descending part of the space plane trajectory the altitude decrease in the range 40-10 km is less steep than the ascending part that is why the Photzer maximum close to 20 km altitude is better observed. The overestimation of the averaged dose rates of more than 5 μGy h^{-1} is because of high energy depositions in the mentioned above spectra.

The decrease of the altitude in the range from 10 to 1.4 km return the dose rates to the average values of 0.098 μGy h^{-1}, which is larger than the observed during the ascending part of the flight at fixed altitude of 1.3 km.

Comparison of Liulin-CNR-VG altitudinal profile with previous observation with Liulin instruments at stratospheric balloons and aircraft

Figure 3.a presents the result of the comparison between absorbed dose rate altitudinal profile obtained by Liulin-CNR-VG instrument on the descending part of the VG space plane (blue points and line) and Liulin and TEPC instruments flown on stratospheric balloons from Fort Sumner, New Mexico in 2005 and 2015.

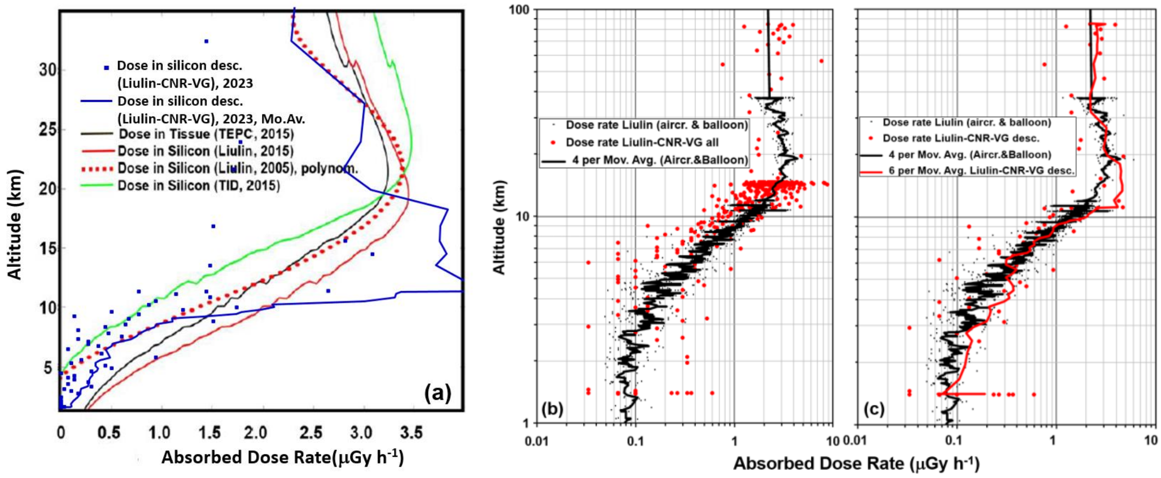

Fig. 3.a Fig. 3.b Fig. 3.c

Fig. 3.a Comparison between absorbed dose rate profiles obtained by Liulin-CNR-VG instrument (blue points and line) and Liulin and TEPC instruments flown on stratospheric balloons in 2005 and 2015;
3.b Comparison between all absorbed dose rate data obtained by Liulin-CNR-VG and Liulin-4C MDU-5 on commercial aircraft flights at altitudes between 1 and 11.9 km and by MDU1 of Liulin-4U instrument on stratospheric balloon between 11.9 and 37 km (small black points)
3.c. The same aircraft and balloon Liulin data as on 3.b. The Liulin-CNR-VG descending part of the trajectory is shown with red points and the moving average curve over six points is presented as red line.

The first balloon flight, with three movable dosimetry units (MDUs), was on 8 June 2005 during the certification flight of the NASA Deep Space Test Bed (DSTB) balloon at Ft. Sumner 104.24°W, 34.47°N, New Mexico, USA [7]. The dotted red line on Fig. 3.a presents the altitude profile between 0 and 37 km altitude obtained from the un-shielded MDU. The maximal dose rate measured in the Pfotzer maximum was 3.5-μGy h^{-1}.

The coordinates of the VG Spaceport America are 106.95W 32.98°N. SpaceShipTwo take off and land after almost a vertical flight up to 85.1 km. The difference in the coordinates between the Spaceport America and Ft. Sumner is neglectful for the space radiation profile, as it is only 2-3 degrees. That is why we may consider that the data, obtained during this balloon flight, are relevant to be compared with the VG flight in 2023.

The second balloon flight was the NASA high-altitude RaD-X mission [8]. It was fulfilled again from Ft. Sumner on 25 of September 2015. Four radiation dosimeters were on the board of RaD-X: a Far West HAWK tissue equivalent proportional counter (TEPC version 3) (https://www.fwt.com/detector/fw-ad1ds.htm), a Teledyne dosimeter (UDOS001), a Liulin dosimeter (MDU 6SA1) and a RaySure dosimeter (version 3b). Fig. 3.a here is an extended version of Fig 10 from [8] as VG flight is included. Three altitude profiles from the flight in 2015 are depicted. The Liulin-6SA1 profile observed with 60 sec resolution is with a red line. It is seen that the Liulin-6SA1 profile is very similar to TEPC (black line) and TID (green line) profiles. The latter once again confirms the Liulin instruments quality of measurements. The three profiles from the TEPC, TID and Liulin-6SA1 seen in Fig. 3.a do have almost linear rise in the range from ground up to 15-16 km altitude. The polynomial presentation (4th order) (Fig. 3.a, red dashed line) is used to illustrate Liulin doses obtained during the flight in 2005. As expected, the Liulin profiles in 2005 and 2015 are very similar.

The dose rate profile got during the descending part of the flight of Virgin Galactic SpaceShip Two on 29 June 2023 is presented with blue points and blue line for the Moving average curve. It is seen that the relatively small amount of blue points in general followed the previous measurements. The moving average over 15 points blue curve in the upper and lower part of Fig 3.a also in general followed the other curves. The strong discrepancy in the altitudinal range between 10 and 20 km altitude we attribute to the small statistics in the Liulin-CNR-VG spectra, obtained with 10 s resolution.

Fig. 3.b presents the result of the comparison between all absorbed dose rate data obtained by Liulin-CNR-VG and Liulin-4C MDU-5 on commercial aircraft flights with 10 minutes resolution at altitudes between 1 and 11.9 km and by MDU1 of Liulin-4U instrument [7] on stratospheric balloon between 11.9 and 37 km with 1 minute resolution (small black points and Moving average over 4 points black curves). All Liulin-CNR-VG data are shown with red points. In general, the Liulin-CNR-VG absorbed dose rate data followed the aircraft and balloon data. The reason for the large dispersion of Liulin-CNR-VG data as already mentioned is the 10 sec resolution of these data.

Fig. 3.c contains the same aircraft and balloon Liulin data as Fig. 3.b. The Liulin-CNR-VG descending part of the trajectory is shown with red points and moving average curve over six points. It is seen that the Liulin-CNR-VG deposited dose rate moving average red curve relatively well coincides with the aircraft and balloon moving average over 4 points black curve in the upper and lower part of the figure. In the altitudinal range from 10 to 20 km there exist broad maximum from which it is hard to decide where exactly the Pfotzer maximum is.

Conclusions

The equivalent dose during the flight of Virgin Galactic SpaceShip Two is calculated from the Liulin-CNR-VG data to be about 5.18 μSv for 2.37 hours (2.19 μSv h^{-1}) because the mean quality factor for a subsonic flight is about 1.8 (2.88*1.8=5.18 μSv) [9]. A passenger, flying from London to New York at a height of 11 km, received for ~7 hours a dose of 32 μSv (4.6 μSv h-1) (https://radioactivity.eu.com/in_daily_life/radioactivity_in_flight). This is slightly over of 25 μSv, which is the equivalent of a panoramic dental X-ray scan https://www.radiologyinfo.org/en/info/safety-xray. On the other hand, the calculated accumulated equivalent dose of 5.18 μSv is 6.18 times less from the dose resulting from a London - New York flight. The measured values for the hourly dose rate of 2.19 μSv h-1 and accumulated dose of 5.18 μSv reveal that there is no space radiation risk for the pilots and astronauts flying at the VG SpaceShipTwo up to 85.1 km altitude on 29 June 2023.

Acknowledgements

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

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