Bulgarian Academy of Sciences. Space Research and Technology Institute.
Aerospace Research in Bulgaria. 24, 2012, Sofia

OVERVIEW OF THE ATMOSPHERIC IONIZING RADIATION ENVIRONMENT MONITORING BY BULGARIAN BUILD INSTRUMENTS

Tsvetan Dachev[1], Borislav Tomov[1], Yury Matviichuk[1], Plamen Dimitrov[1], Frantisek Spurny[2], Ondrej Ploc[2], Yukio Uchihori[3], Erwin Flueckiger[4], Karel Kudela[5], Eric Benton[6]

[1]Space Research and Technology Institute – Bulgarian Academy of Sciences, tdachev@bas.bg, btomov@bas.bg, yumat@bas.bg, pdimitrov1957@abv.bg
[2]Nuclear Physics Institute – Czech Acad. Sci., ploc@ujf.cas.cz
[3]National Institute of Radiological Sciences, Chiba, Japan, uchihori@nirs.go.jp
[4]Physikalisches Institut, University of Bern, Switzerland, flueckiger@space.unibe.ch
[5]Ústav experimentálnej fyziky SAV, Oddelenie kozmickej fyziky, Košice, Slovakia, kkudela@kosice.upsj.sk;
[6]Oklahoma State University, Stillwater, OK, USA, eric.benton@okstate.edu

Abstract

Humans are exposed to ionizing radiation all the time, and it is known that it can induce a variety of harmful biological effects. Consequently, it is necessary to quantitatively assess the level of exposure to this radiation as the basis for estimating risks for their health. Spacecraft and aircraft crews are exposed to elevated levels of cosmic radiation of galactic and solar origin and to secondary radiation produced in the atmosphere, the vehicle structure and its contents. The aircraft crew monitoring is required by the following recommendations of the International Commission on Radiological Protection (ICRP) (ICRP 1990), the European Union (EU) introduced a revised Basic Safety Standards Directive (EC 1997) which, inter alia, included the exposure to cosmic radiation. This approach has been also adopted in other official documents (NCRP 2002). In this overview we present the results of ground based, mountain peaks, aircraft, balloon and rocket radiation environment monitoring by means of a Si-diode energy deposition spectrometer Liulin type developed first in Bulgarian Academy of Sciences (BAS) for the purposes of the space radiation monitoring at MIR and International Space Station (ISS). These spectrometers-dosemeters are further developed, calibrated and used by scientific groups in different countries. Calibration procedures of them are performed at different *accelerators including runs in the CERN high-energy reference field, simulating the radiation field at 10 km altitude in the atmosphere and with heavy ions in Chiba, Japan HIMAC accelerator were performed also. The long term aircraft data base were accumulated using specially developed battery operated instrument in 2001-2009 years onboard of A310-300 aircrafts of Czech Air Lines, during 24 about 2 months runs with more than 2000 flights and 13500 flight hours on routes over the Atlantic Ocean mainly. The obtained experimental data are compared with computational models like CARI and EPCARD. The mountain peak measurements are performed with Liulin-6S, Liulin-6MB and Liulin-6M internet based instruments. They use internet module to generate WEB page, which is posted online. The obtained deposited energy spectra, dose and flux data are transmitted via LAN interface by HTTP and FTP protocols. They work online for different periods between 2005 and 2011 at Jungfrau (3453 meters Above Mean Sea Level (AMSL) http://130.92.231.184/); at Lomnicky stit (2633 meters AMSL http://147.213.218.13/) and Moussala (2925 meters AMSL http://beo-db.inrne.bas.bg/moussala/) peaks in Switzerland, Slovakia and Bulgaria. 4 small size battery operated instruments were flown on balloon over south France in June 2000 and NASA balloon over New Mexico, USA on 11^{th} of June 2005. 1 instrument was used in rocket experiment January 2008.*

1. Introduction

Ionization in the lower atmosphere is dominated by radionuclides in the Earth's crust. Over deep water, there are few dissolved radionuclides so that the ionization is dominated by radiation incident on the top of the atmosphere. The ionization over the landmass is complicated and depends on many physical and chemical factors. V. F. Hess studies found the ionization rates to decrease with altitude up to 500 meters followed by a steady increase at higher altitudes to where the ground level rate is matched at 1500 meters. For this discovery, Hess would receive a Noble prize in physics (1936) [1].

The space radiation sources as Galactic cosmic rays (GCR) and Solar cosmic rays (SCR) penetrate deep in the atmosphere where the primary protons generate a cascade of particles (protons, neutrons, pions, muons, electrons and gamma quants) [2]. The first reactions of the cosmic rays with the atmosphere occur at altitudes above 20 km. Down at altitudes 19-20 km is recognized the so-called Photzer maximum [3]. This is the main maximum of the ionization and of dose rates profile in the Earth atmosphere and reach about 3 μGy h^{-1}. At aircraft altitudes (10-12 km) the neutron flux dominate and generate about 10% of the absorbed dose but 59% of the ambient equivalent dose. Earth magnetic field shields atmosphere from the primary and secondary cosmic rays that is why the maximum of the latitudinal profile is at high magnetic latitudes. Close to the magnetic equator is formed the absolute minimum of the ionizing radiation at aircraft altitudes [4,5].

The solar activity also modulates the atmospheric ionizing radiation through the modulation of the GCR flux. Interplanetary magnetic field, which is embedded in the solar wind shield the heliosphere from GCR and this, is the reason for observation of maximum of the GCR flux and respectively the dose rates in atmosphere close to the minimum of the solar cycle. In reverse close to the maximum of the solar cycle a minimum of the GCR flux is observed [5].

1. Description of the Liulin type instruments used for atmospheric radiation monitoring

The main purpose of Liulin type Spectrometry-Dosimetry Instruments (LSDIs) is cosmic radiation monitoring in the atmosphere at the workplaces. LSDI measures the amplitudes of the pulses generated by the incoming particle and rays radiation in the silicon detector, which is proportional to the deposited energy and respectively to the absorbed dose in Gray. These amplitudes are organized in 256 channels spectrum of the deposited energy in the silicon detector, which is further used for precise calculation of the absorbed and equivalent doses and for characterization of the type and energy of the incoming radiation. Up to now more than 20 LSDIs were developed, build and used on the ground, in aircraft altitudes, in Low Earth Orbits (LEO) and inside and outside of the Earth magnetosphere and on the Moon orbit [6].

First use of Liulin type LSDI were in the Mobile Radiation Exposure Control System - Liulin-E094, which contains 4 active individual dosemeters and worked successfully between May and August 2001 on board of US Laboratory module of the International Space Station (ISS) as a part of the ESA Dosimetric mapping experiment leaded by Dr. Günter Reitz, DLR, Germany [7, 8].

The LSDI functionally is low mass, low power consumption or battery operated dosimeter. The smallest one built till now is the RADOM instrument (98 grams) used for measurement of the near Moon radiation environment on the first Indian Moon satellite – Chandrayaan-1 in 2008-2009 [9, 10]. The largest modifications (450 grams) are these with 2 lithium-ion batteries, Global Positioning System (GPS) receiver and Secure

Digital (SD) card for about a month of independent recording of the radiation environment and the UTC time and geographic coordinates at aircraft altitudes [11]. (See Figure 1.)

Fig. 1. LSDI with GPS receiver and SD card for continues dose monitoring at aircrafts

Except the already mentioned devices, since 2001 following examples of LSDIs have been used on ground, on board aircrafts, balloons and rockets:

Mobile Dosimetry Units MDU-5 and 6 was used for more than 13500 hours between 2001 and 2009 on Czech Airlines (CSA) aircraft at different routes as comparison measurement with aircraft crew individual dosimetry. The experiments and data analysis were managed by Prof. F. Spurny [12];

The Liulin-MDU-2 instrument work successfully during the flight of French balloon up to 32 km altitude in the region of the Gap town in Southern France on 14th of June 2000. This experiment was performed by the Nuclear Physics Institute, Czech Academy of Sciences [13].

One battery-powered LSDIs of Liulin-4J type perform dosimetric measurements of the ionizing radiation environment at ~20 km altitude aboard NASA’s Lockheed ER-2 high altitude research aircraft in October-November 2000 from Edwards Air Force Base (AFB) in Southern California and flew over the border region dividing Central California from Central Nevada [14].

Three battery-powered LSDIs were operated during the 8 June 2005 certification flight of the NASA Deep Space Test Bed (DSTB) balloon at Ft. Sumner, New Mexico, USA. The duration of the flight was about 10 hours [15];

Liulin-R was successfully launched on HotPay2 rocket from Andoya Rocket Range (ARR), Norway, on 31st of January, 2008 at 19:14:00 and rising up to 380 km altitude, as a part of an EU financed scientific program called eARI (ALOMAR eARI project) [16];

Liulin-6S, Lilun-M, Liulin-6MB and Liulin-6R are internet based instruments. They use internet module to generate web page. The obtained deposited energy spectra data are transmitted via LAN interface by HTTP and FTP protocols. They worked for different periods since 2005 at Jungfrau (Switzerland) 3453 meters Above Mean Sea Level (AMSL) http://130.92.231.184/), Moussala (Bulgaria) 2925 meters AMSL http://beo-db.inrne.bas.bg/moussala/ and Lomnicky Stit (Slovakia) 2633 meters AMSL http://147.213.218.13/ peaks and at ALOMAR observatory in Norway (http://128.39.135.6/) [17]. The three peak instruments are working well till now (March 2011) and their data can be obtained online on the mentioned above addresses;

Very similar instruments to the Mobile Dosimetry Units MDU-5 and 6 are used by scientific groups in Spain [18] and Germany [19] for radiation measurements at aircrafts.

2.1. Block diagram explanation

LSDI usually contains: one semiconductor detector, one charge-sensitive preamplifier, a fast 12 channel analog-to-digital converter (ADC), discriminator, real time clock, 2 or more microcontrollers and a flash memory. Different modifications of LSDI use additional modules such as: UV sensitive photo diodes, temperature sensor, Global Positioning System (GPS) with antenna and receiver, display (see Figure 2.), multimedia card (MMC) or SD cards. Figure 3 presents a generalized block schema of Liulin type spectrometers.

Fig. 2. LSDI with LCD display

The unit is managed by the microcontrollers through specially developed firmware. Plug-in links provide the transmission of the stored on the memory data toward the standard Personal Computer (PC) or toward the telemetry system of the carrier. A computer program in PC is used for the full management of the LSDI through standard serial/parallel or USB communication port. The same program stores the full data sets on the PC and visualizes the data for preliminary analysis.

Different power supplies were used in the different instruments. They are presented on the upper part of Figure 1 and include 3.6 V or 7.2 V rechargeable or primary batteries, 28 V or 43 V DC aircraft and satellite power and 110 V, 400 Hz AC aircraft power line.

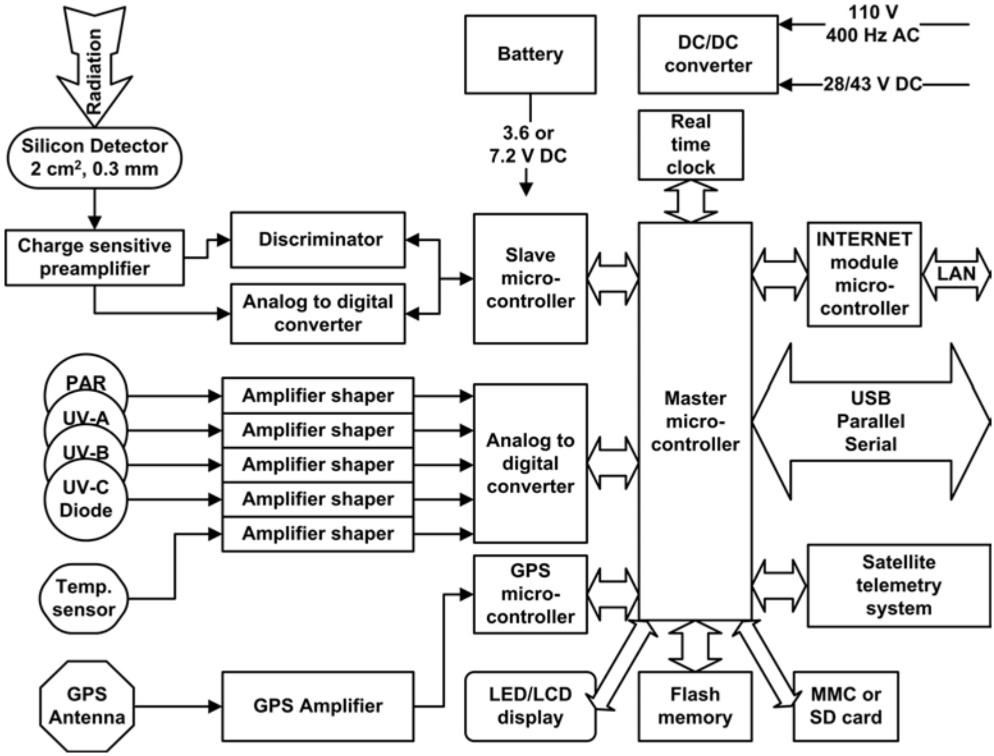

Fig. 3. Generalized block-diagram of Liulin type instruments

1.2. Dose interpretation procedure

The spectrometers measure the pre-amplified amplitude of pulses generated by particles or quantum hitting the detector. The amplitude is proportional by a factor of 240 $mV.MeV^{-1}$ to the energy loss in the detector and respectively to the dose and Linear Energy Transfer (LET). By the 12 bit ADC these amplitudes are digitized and organized in a 256-channel spectrum using only the first 8 bits of the ADC. The dose D [Gy] by definition is one Joule deposited in 1kg. We calculate the absorbed dose by dividing the summarized energy deposition in the spectrum in Joules to the mass of the detector in kilograms.

$$D = K\sum_{i=1}^{256} i k_i A_i m_D^{-1} \quad (1)$$

where m_D is the mass of the detector in kg, k_i is the number of pulses in channel “i”, A_i is the amplitude in volts of pulses in channel “i”, $K.i.k_i.A_i$ is the deposited energy (energy loss) in Joules in channel “i”. K is a coefficient. All 256 deposited dose values, depending on the deposited energy for one exposure time, form the deposited energy spectrum.

In 2001 F. Spurny developed a procedure, which allows the calculation of the ambient dose equivalent from the deposited energy spectrum [20]. The procedure was further developed by O. Ploc [21].

2. Calibration results

LSDIs were calibrated in wide range of radiation fields. First it was irradiated in gamma and neutron (^{137}Cs, ^{60}Co, AmBe, and ^{252}Cf) radiation fields [22]. The calibrations revealed that except for charged energetic particles, the detector has high effectiveness toward gamma rays. Detector’s neutron effectiveness depends on their energy [22].

LSDIs have been calibrated in the CERN-EU energy reference field behind the concrete shield [23]. The fluence energy spectra of neutrons registered there are very similar to the spectra on the aircraft and/or balloon [20].

Eight batteries operated LSDIs were tested in CERN-EU high-energy reference field in July 2003. All 8 instruments were irradiated at the same time by exposing their Si-diode surfaces parallel to the concrete wall at the distance of 15 cm between the diodes and the side wall of the concrete shielding. The relative LSDIs dose rates depend by correction factors from their positions. The correction factors assessment is based on the results obtained by CERN collaborators Mitaroff & Silari [18], taking into account that the most part of doses is due to low LET component (muon background) of the field. The time structure of the beam was within a pulse cycle lasting 16.8 s and particles were impinging on the target for 5.1 s. The level of beam intensity is monitored using a precise ionization chamber (PIC). It is expressed in terms of number of PIC impulses per 1 spill of the accelerator.

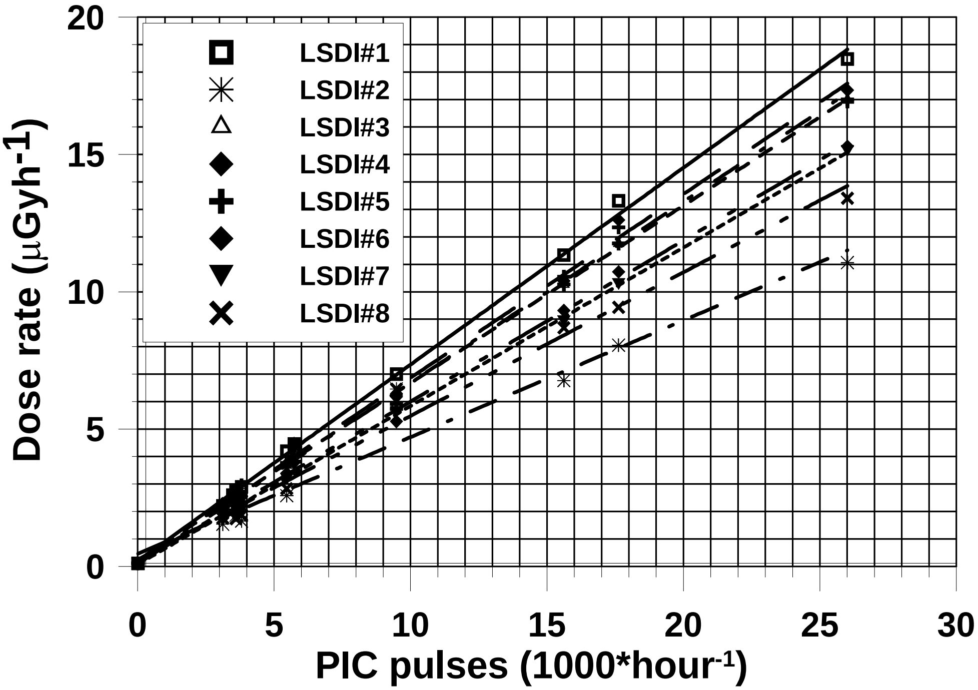

Fig. 4. Linear regressions of the total absorbed dose rates in silicon as a function of the beam intensity for 8 different LSDIs.

Figure 4 represents the obtained by the eight different LSDIs linear regressions of the total dose in Silicon detectors rates as a function of the beam intensity represented with the number of PIC impulses. Nice linear increase of the dose rates in each LSDI is observed when the beam intensity increase. The differences in the slope of the linear curves are found to depend mainly from the position in the field and therefore their reference values [23].

LSDIs were calibrated, including the dependence of energy deposition in the detector on the direction of the incident radiation at the cyclotron facilities of the Indiana University [24], University of Louvain, Belgium [7] and of the National Institute of Radiological Sciences-STA, Chiba, Japan [25] with protons of energies up to 190 MeV. In all protons calibrations good agreement was obtained between the experimental and simulated with GEANT4 code spectra.

Finally LSDIs was calibrated at heavy ions fluxes up to 500 MeV/u iron ions at HIMAC, Japan irradiation facility [7, 25]. Heavy ion experiments also confirmed that the dosimeter can measure the fragmentation of heavy ions and it was established that instrument's energy resolution is sufficient to distinguish the charge peaks of the individual fragment ions [25].

In-flight intercalibration between LSDI and commercial available TEPC were obtained by Canadian group during a flight from Singapore to London on 2 December 2003 and show nice agreement [26].

4. Experimental Results

4.1. General presentation of the deposited dose spectra shapes and slopes

Figure 5 presents examples of the averaged spectra shapes and slopes from ground, mountain peak Jungfrau, aircraft and spacecraft (Please look the top part of the figure). The individual spectra seen on this figure are obtained after averaging of various numbers of primary spectra and are plotted in coordinates Deposited energy/Deposited dose rate. The main idea of the figure is that the spectra shapes and slopes characterize the predominant type of radiation where the data are taken from [6]. Spectra are grouped by the predominant type of radiation: Lowest blue shadowed is from Galactic Cosmic Rays (GCR), while middle (yellow shadowed) is from protons from South Atlantic Anomaly (SAA). The top magenta shadowed group of curves is from Outer Radiation Belt (ORB) electrons.

From bottom to top the spectra are arranged depending on the value of the deposited dose rates seen in the middle part of the figure. Lowest is from ground natural radiation of 0.12 μGy h^{-1}, while the highest spectra of 9000 μGy h^{-1} is from relativistic electrons measurements at ISS [27].

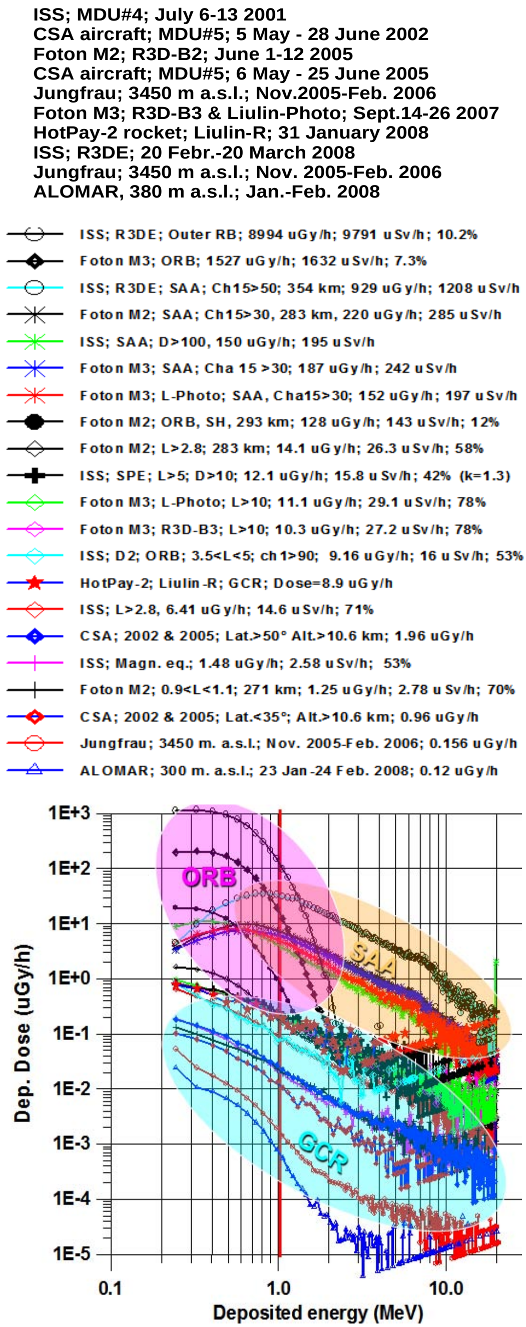

Fig. 5. General presentation of the deposited dose spectra obtained during different experiments in the atmosphere and space.

4.2. Ground based and mountain peak results

The ground based measurements in usual low solar activity conditions obtain the activity from the radioactive isotopes in the ground below the instrument. This type and the Radon gas radiation predominates there and gives about 60% of the total dose, which usual values vary between 0.04 and 0.15 μGy/h. The GCR primary and secondary particles give only 13% of these doses [28]. These type of data were obtained by us by the Liulin-6R instrument located at the ALOMAR observatory at about 380 meters above the see level during the flight of HotPay-2 rocket experiment up to 380 km from Andoya Rocket Range, Norway on January 31st 2008 [16]. As expected on Figure 5 this is the lowest curve.

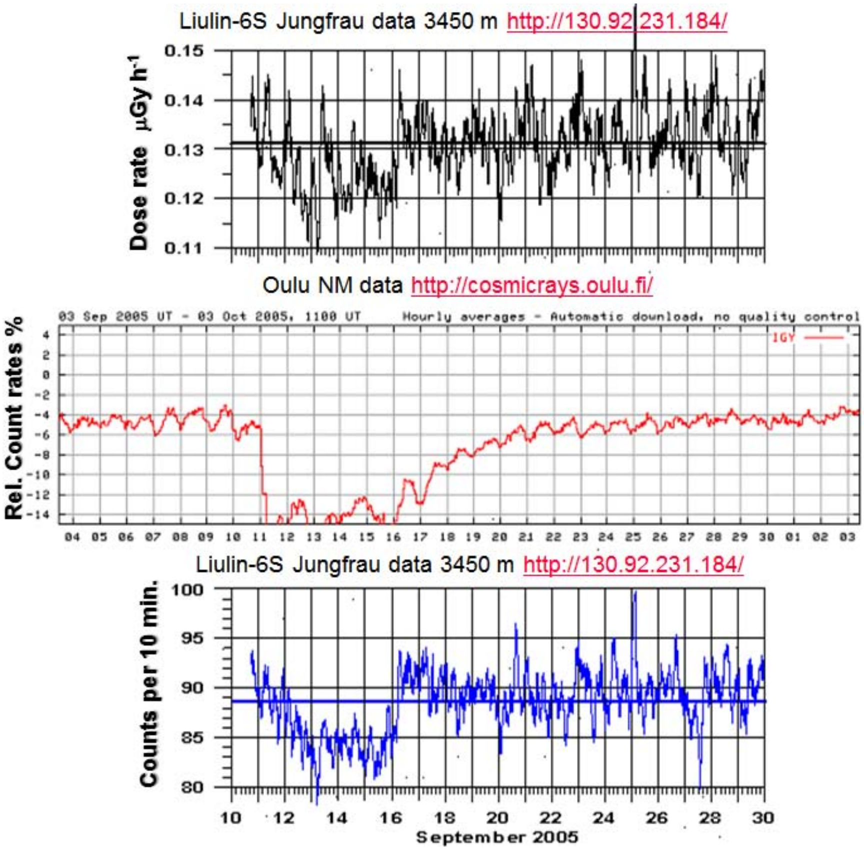

Fig. 6. Comparison of the variations of the Jungfrau dose and count rate with the Oulu NM relative count rate data around the Forbush decrease in September 2005.

The absorbed dose spectra measured at the 3 mountain peaks Jungfrau (3453 m), Mousala (2925 m) and Lomnicky stit (2633 m) are more similar to the aircraft spectra than to the ground based measurements (Please see Figure 5).

The comparison of the Jungfrau count and dose rate data (3450 m) with the Oulu NM http://cosmicrays.oulu.fi/ relative count rate data (Please see Figure 6) obtained around the Forbush decrease in September 2005 show that Liulin type spectrometers can be used effectively to monitor the amount of primary and secondary GCR particles at mountain peaks. The ALOMAR station data don't show dependence by Forbush decrease.

4.3. Aircraft results

The aircraft spectra on Figure 5 are in the middle of the blue shadowed area and are very similar but with lower doses to the spacecraft GCR spectra.

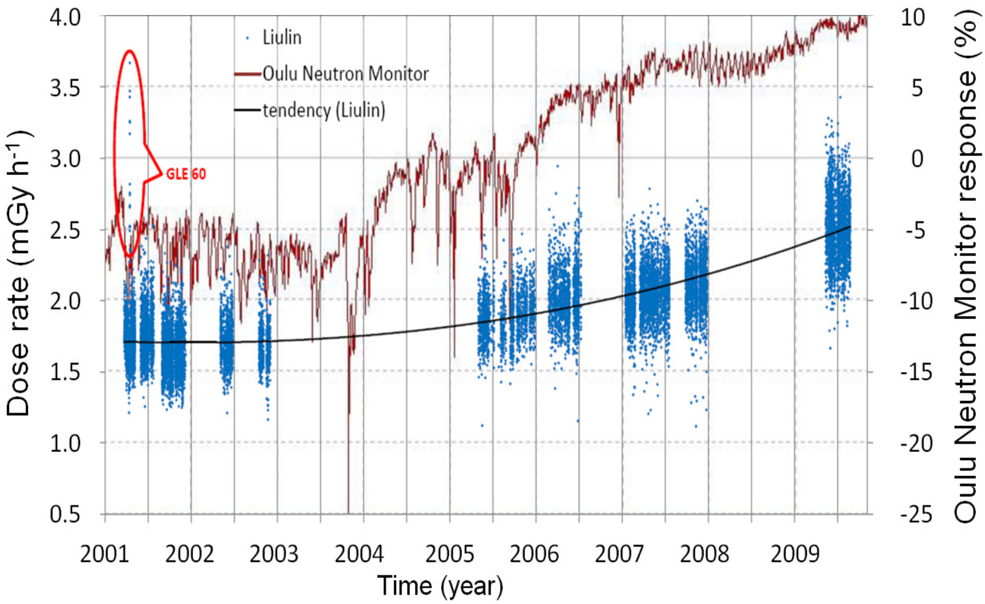

Fig. 7. Variations of the average deposited dose rate for transatlantic flights at altitude 10.6 km

Figure 7 summarizes all data obtained by 2 Liulin type instruments on CSA aircraft between 2001 and 2009. All data in the period 2001-2007 was collected by the MDU#5 instrument. The data in 2009 was measured with a new build instrument, which have almost same characteristics as MDU#5. More than 64000 measurements with 10 minutes resolution are presented on the figure. Each patches of data were obtained in about 1-3 months of continues measurements campaign. Mostly aircraft flights on the destinations Prague - New York and Prague - Toronto at fixed altitude of 35000 feet (10.6km) are used. The cut-off rigidity varies between 0.16 and 2.0 GV when the latitude changes between 50 and 65°.

On the X axis is plotted the date between January 2001 and October 2009. On the left hand Y axis the measured absorbed dose rate in the silicon of the detector is plotted. The right hand Y axis is for the Oulu Neutron Monitor response in percent. The Oulu data http://cosmicrays.oulu.fi/ are seen on the figure as continues heavy black line, which varies in average between -7% in the maximum of the solar activity (2001-2004) and +9% in the minimum of solar activity in 2009.

The Liulin data rises in average from about 1.75 to 2.5 $\mu Gy\ h^{-1}$. This tendency is presented on the plot by polynomial fit of data shown as black line through them. The dose rates obtained during the solar proton event and Ground Level Enhancement on 15th of April 2001 (GLE 60) (Spurny and Dachev, 2001) form the absolute maximum in the data and are specially mentioned in the left hand side of the picture. The increase of the GCR data in 2009 shows single points, which are comparable with those obtained during GLE 60. The calculated apparent dose equivalent dose rates shows very similar to the presented at Figure 1 variations but in an average range from 4-6 $\mu Sv\ h^{-1}$. Some extreme high measurements in 2009 reach values of 11 $\mu Sv\ h^{-1}$.

Figure 8 was specially designed to present how closer the measured GCR dose rates and fluxes on aircraft and spacecraft are. There are 2 panels on the figure. The X axes is for the geographic latitude in the range from 0 to 70° in the Northern hemisphere. The data in the figure are selected from relatively narrow longitudinal range – ±40° from the Greenwich meridian. Two facts allow us to conclude that only GCR data are separated: 1) This latitudinal and longitudinal range is away from the region of the South Atlantic Anomaly (SAA); 2) There are no Solar Proton Events in the mentioned above time intervals.

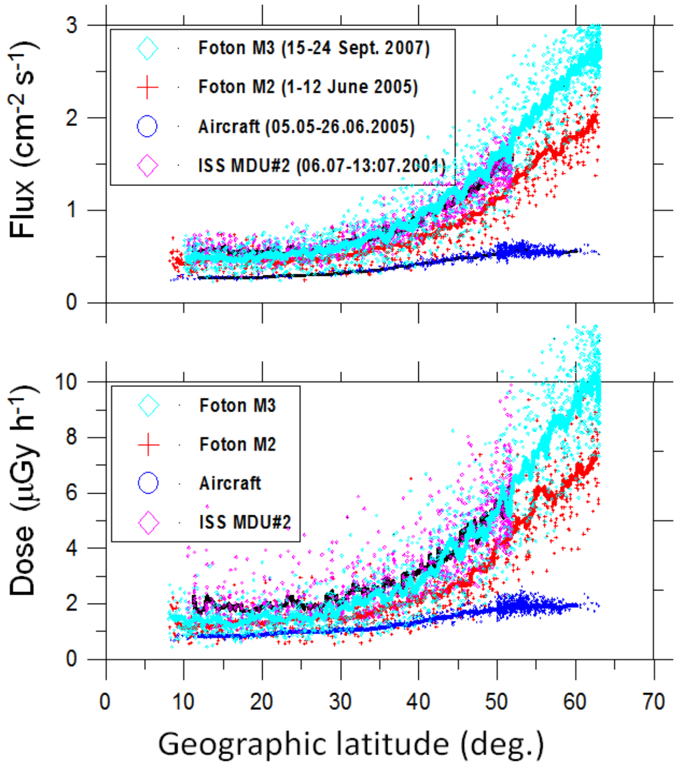

Fig. 8. Latitudinal profiles of the dose rate and fluxes at aircraft, Foton M2/M3 spacecraft and ISS.

In the panels are presented the measured absorbed dose rates (bottom panel) and fluxes (top panel) at 4 vehicles, which data are taken for the periods and altitudes as follows: Aircraft -05.05-26.06 2005 at 10.6 km; Foton M2 1-12 June 2005 at 260 km; Foton M3 15-24 September 2007 at 267 km; ISS (MDU#2) 6-13 July 2001 at 393 km.

The main results from the analysis of Figure 7 are: 1) All latitudinal profiles shows similar shape with minimum at low latitudes and rising values toward high latitudes; 2) In the range 10-30° the values are practically independent from the latitude. The averaged dose rates in this range are 0.66 µGy h^{-1} at aircraft, 1.34 µGy h^{-1} at Foton M3/M3 satellite and 1.93 µGy h^{-1} at ISS. Simple calculations reveal that the ratios of the dose rates in this range at altitudes 10.6, 260 and 393 km are as 1:2:3 i.e. the GCR component of the Earth radiation environment is attenuated only 3 times from the Earth magnetic field and atmosphere on it path from space to the ground; 3) The aircraft dose rates and fluxes shows almost fixed values in the range 50-60°.

4.5. Balloon results

One MDU of the Liulin-4C system has been exposed on the balloon launched the 14 June 2000 at the Gap (France). The altitude, the effective dose profile calculated by means of the CARI-6 code and the dose in Si, D(Si), profiles directly measured with Liulin-4C are presented in the Figure 9 [13]. All dosimetric data well present the Photzer maximums [3] at about 1 hour and 5.2 hours after the launch.

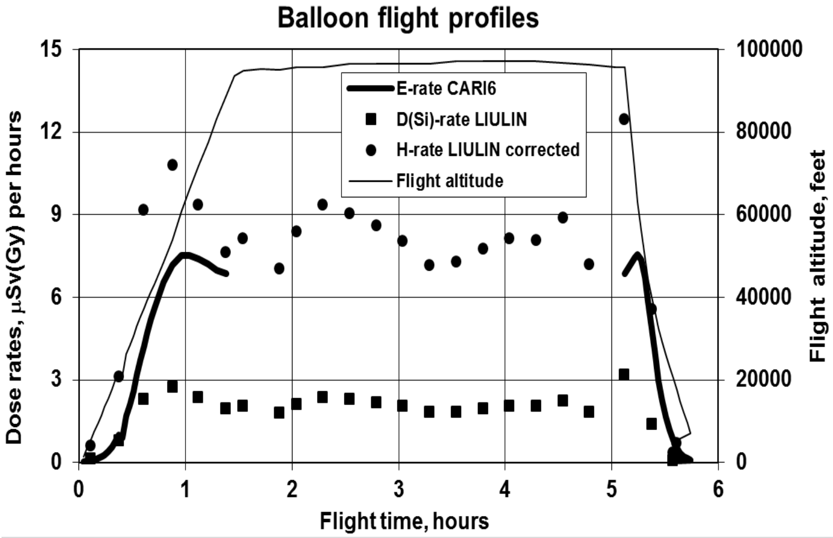

Fig. 9. Profiles obtained by one of the MDUs of Liulin-4C system during balloon flight over the French Gap town on 14th of June 2000.

We transform the dose rates in Si determined on the balloon board to the dose equivalent rates (H-rate) based on the CERN reference field. The results obtained are graphically presented in the Figure 9, together with the values calculated by means of the CARI-6 code [29]. One can see from Figure 9 that the values of dose equivalent deduced from the Liulin-4C data on the base of CERN calibration are much closer to the effective dose values calculated by means of the CARI6 code. They are generally higher, about 20-30 %, due to the difference in the relative contributions of low and high LET components in on balloon board and CERN reference field.

Three battery-powered LSDIs were operated during the 8 June 2005 certification flight of the NASA Deep Space Test Bed (DSTB) balloon at Ft. Sumner, New Mexico, USA. The duration of the flight was about 10 hours [15].

The DSTB was launched from Ft. Sumner, NM at 09:45 Mountain Daylight Time (MDT). The three Liulin-4 MDUs measured particle flux and dose rate as functions of time at one minute intervals during. Figure 10 shows flux as a function of time as measured by the three MDUs, as well as altitude as provided by the DSTB GPS receiver, together barometric altitude, as functions of time.

All three MDUs measured similar flux and dose rate profiles and these profiles correlate well with the altitude profiles. Following launch at 09:45 MDT, there is a rapid increase in flux and dose rate as the balloon gains altitude. Both flux and dose rate reach a maximum at ~70,000 ft. altitude (21.3 km) and then fall off as altitude continues to increase. The altitude of maximum flux and dose rate is the Photzer Maximum, the altitude at which the showers or cascades of secondary particles produced by primary cosmic rays interacting with the constituent nuclei of the atmosphere are most intense. Shortly before 12:00 MDT, the DSTB attained its maximum cruising altitude of ~120,000 ft. (36.5 km) and both flux and dose rate levelled off. Flux and dose rate remained fairly constant for the remainder of the flight and only began to change at 18:45 when the DSTB gondola was released from the balloon and began its rapid descent toward the ground. The flux and dose rate measured by MDU #5 during the high altitude cruise phase shows considerably more variation than do the measurements made by MDU #1 and MDU #2. This is because MDU#5 was exposed beneath the shielding carousel at the centre of the DSTB platform and the carousel was repeatedly rotated during the flight in order to test its operation. As a result, the shielding environment immediately above the MDU #5 detector repeatedly changed over the course of the flight.

The most interesting observation from these results is that higher values of flux and dose are for MDU #2 under 5 g cm^{-2} Al shielding and for MDU #5 under the carousel, and not for MDU #1 which was relatively unshielded. This result runs contrary to expectations that the larger amounts of shielding would attenuate the flux and thereby reduce the dose rate.

4.3. Rocket results

Liulin-R was successfully launched on HotPay2 rocket from Andoya Rocket Range (ARR), Norway, on 31st of January, 2008 at 19:14:00 and rising up to 380 km altitude, as a part of an EU financed scientific program called eARI (ALOMAR eARI project) [16].

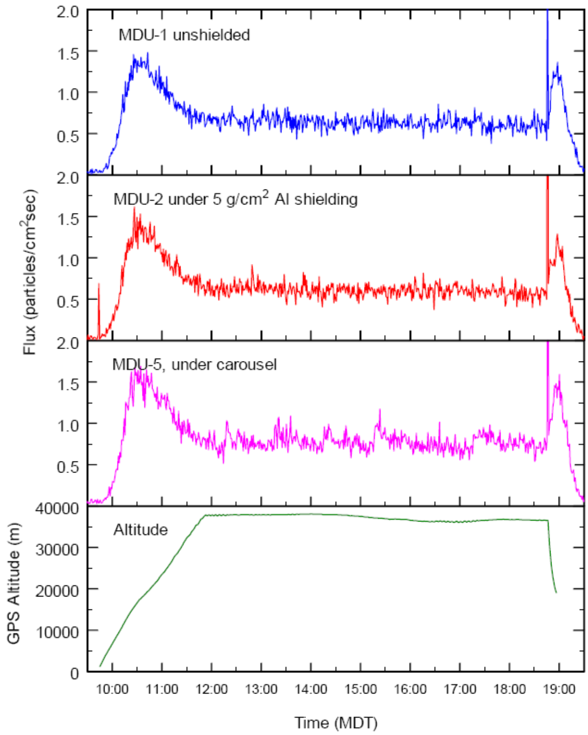

Fig. 10. Flux profiles measured by the three Liulin-4 MDUs exposed during the 8 June 2005 DSTB certification flight. Also shown is the GPS altitude profile in meters.

Figure 10 represent the obtained dose rate (red line) and flux (blue line) data in dependence by the altitude of the rocket. We believe the ascending data up to 150 km of altitude are corrupted by the rocket vibrations, which were infused by the burning in this phase engine. Next between altitude of 200 km up to the apogee of the rocket flight (380 km) the dose rate and flux remain almost fixed in both ascending and descending parts of the flight. The dose rate values of about 10 μGy h^{-1} are close to the observed at similar altitudes GCR values on spacecraft [6]. Also the obtained deposited energy average spectrum, shown on Figure 5 with blue line and red stars is exactly inside of the bunch of curves from satellites.

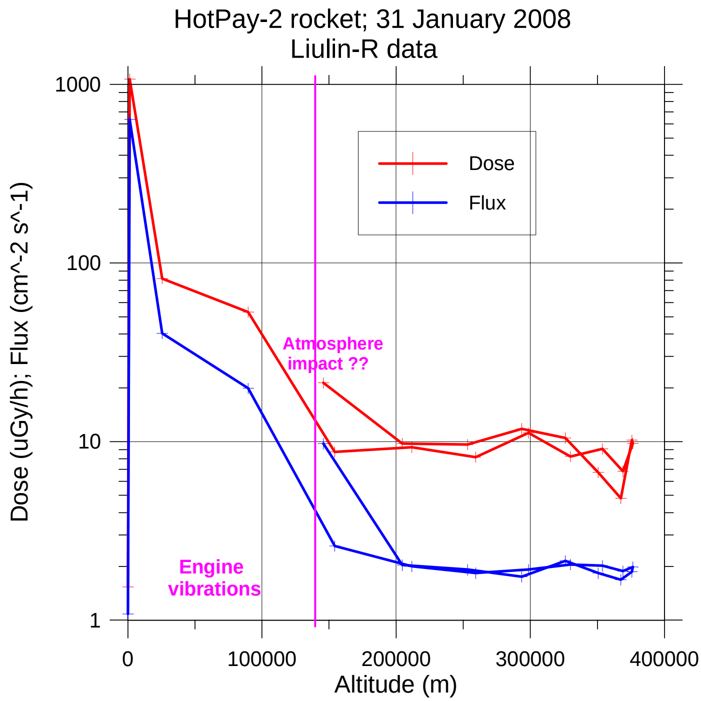

Fig. 11. Liulin-R data during the flight of HotPay-2 rocket experiment up to 380 km on January 31st 2008, Andoya Rocket Range, Norway.

Further when on the descending part of the trajectory the rocket reached the higher atmosphere density regions the data were interrupted probably because of the generated impact in the atmosphere.

Altitudinal, latitudinal or longitudinal dependence of the flux and dose are not observed along the HotPay-2 trajectory above 200 km altitude.

Conclusions

The presented LSDI data at various carriers prove very well the ability of these instruments to be used for monitoring of the atmospheric ionizing radiation environment.

Main advantage of the Liulin type spectrometers are their low weight (~100 g), low power consumption (~100 mW), low cost (~ 10000 Euro). The high scientific and application value of the obtained data is coming mainly from the extensive calibrations at different accelerators and from well-developed data analysis procedures.

Acknowledgments

This work is partially supported by the Bulgarian Academy of Sciences and contract DID 02/8 with the Bulgarian Science Fund.

References

1. W i l s o n, J. W., D. M a i d e n, P. G o l d h a g e n, H. T a i, J. S h i n n, Chapter 2: Overview of Atmospheric Ionizing Radiation. (AIR). http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20030063010_2003072785.pdf
2. De A n g e l i s et al., Radiat. Res., 156, 689-694, 2001.
3. K r a i n e v, M., W. W e b b e r, The medium energy galactic cosmic rays according to the spacecraft and stratospheric data, Preprint № 11, Lebedev Physical Institute, Moscow, 2005.
4. S h e a, M., D. S m a r t, Vertical Cutoff Rigidities for Cosmic Ray Stations Since 1955, 27th International Cosmic Ray Conference, Contributed Papers, 10, 4063-4066, 2001.
5. Group of Experts established under Article 31 of the Euratom treaty, EUROPEAN COMMISSION, Radiation Protection 140, Cosmic Radiation Exposure of Aircraft Crew, Compilation of Measured and Calculated Data, Final Report of EURADOS WG 5 to the Directorate-General for Energy and Transport, Directorate H — Nuclear Energy, Unit H.4 — Radiation Protection, 2004.
6. D a c h e v, Ts. Characterization of near earth radiation environment by Liulin type instruments, Adv. Space Res. 44, 1441-1449, (2009). doi:10.1016/j.asr.2009.08.007
7. D a c h e v, Ts. et al. Calibration results obtained with Liulin-4 type dosimeters. Adv. Space Res. 30, 917-925, (2002). doi:10.1016/S0273-1177(02)00411-8
8. R e i t z, G. et al. Space radiation measurements on-board ISS-the DOSMAP experiment. Rad. Prot. Dos. 116, 374-379, (2005). http://rpd.oxfordjournals.org/cgi/content/abstract/116/1-4/374
9. D a c h e v, Ts. et al. Monitoring Lunar radiation environment: RADOM instrument on Chandrayaan-1, Current Science, 96, 544-546, (2009). http://www.ias.ac.in/currsci/feb252009/544.pdf
10. D a c h e v, Ts. et al. Monitoring of the Earth and Moon radiation environment by the RADOM instrument on Indian Chandrayyan-1 satellite. Preliminary results. 40th

Lunar and Planetary Science Conference, The Woodlands, Texas, USA, March 2-27, 2009. http://www.lpi.usra.edu/meetings/lpsc2009/pdf/1274.pdf

11. D i m i t r o v, Pl., et al. Liulin type spectrometers - last developments. Proceedings of Fundamental Space Research Conference. Sunny Beach, Bulgaria, September 2008, ISSBN 978-954-322-316-9, 334-337, (2008). http://www.stil.bas.bg/FSR/PDF/TOP4Dimitrov_Plamen237123.pdf

12. S p u r n y, F. and D a c h e v T. New results on radiation effects on human health, Acta geophysica, 57, 125-140, 2009. http://www.springerlink.com/content/t2364384842lk5v8/

13. D a c h e v, Ts., F. S p u r n ý, B. T o m o v, P. D i m i t r o v, Y. M a t v i i c h u k, Analysis of the Long Term Dosimetry Results Obtained During Commercial Aircraft Flights, Proceedings of 8th STIL-BAS conference, 131-134, Sofia, December, 2001.

14. U c h i h o r i, Y., et al, Radiation Measurements aboard NASA ER-2 High Altitude Aircraft with the Liulin-4J Portable Spectrometer", Advances Space Research, 32, 41-46, 2003.

15. B e n t o n, E., Deep Space ICCHIBAN: An International Comparison of Space Radiation Dosimeters aboard the NASA Deep Space Test Bed, 10th Workshop for Radiation Monitoring on ISS, Chiba, Japan, 7-9 September 2005. http://www.oma.be/WRMISS/workshops/tenth/pdf/08_benton.pdf

16. T o m o v, B. et al. Galactic and solar cosmic rays study by ground and rocketborne space radiation spectrometers-dosimeters-Liulin-6R and Liulin-R, Proceedings of Fundamental Space Research Conference, ISSBN 978-954-322-316-9, 252-257, 2008. http://www.stil.bas.bg/FSR/PDF/TOP5Tomov_Borislav2242058.pdf

17. D a c h e v, Ts. et al. New Bulgarian build spectrometry-dosimetry instruments–short description, Proceedings of 11-th International Science Conference on Solar-Terrestrial Influences, 195-198, Sofia, 2005. http://www.stil.bas.bg/11conf/Proc/195-198.pdf

18. S á e z V e r g a r a, J. and R. D o m i n g u e z – M o m p e l l R o m á n, The Implementation of Cosmic Radiation Monitoring in Routine Flight Operation of IBERIA Airline of Spain: 1 Y Of Experience of in-Flight Permanent Monitoring, Radiation Protection Dosimetry, 136(4):291-296 2009.

19. W i s s m a n n, F., S. B u r m e i s t e r, E. D ö n s d o r f, B. H e b e r, M. H u b i a k, T. K l a g e s, F. L a n g n e r, T. M ö l l e r, M. M e i e r, Field calibration of dosemeters used for routine measurements at flight altitudes, Radiation Protection Dosimetry, 140, 4, 18 May 2010, Pages 319-325, 2010.

20. S p u r n y, F. and D a c h e v T. On board aircrew dosimetry with a semiconductor spectrometer, Radiation Protection Dosimetry, 100, 525-528, 2002. http://rpd.oxfordjournals.org/cgi/content/abstract/100/1-4/525

21. P l o c, O., F. S p u r n y, Ts. D a c h e v, Use of Energy Depositing Spectrometer for Individual Monitoring of Aircrew, Radiat Prot Dosimetry, 144 (1-4), 611-614, 2011. doi: 10.1093/rpd/ncq505

22. S p u r n y, F., P l o c O. and J a d r n í k o v á I. Spectrometry of Linear Energy Transfer and dosimetry measurements onboard spacecrafts and aircrafts, ISSN 1547-4771, Physics of Particles and Nuclei Letters, 2009, 6, 70–77. © Pleiades Publishing, Ltd., 2009.

23. M i t a r o f f, A. and S i l a r i M. The CERN-EU High-energy reference field (CERF) facility for dosimetry at commercial flight altitudes and in space. Rad. Prot. Dos. 102 7-22 (2002).

24. D a c h e v, Ts. et al. Analysis of the cyclotron facility calibration and aircraft results obtained by LIULIN-3M instrument, Adv. Space Res., 32, 67-71, (2003). doi:10.1016/S0273-1177(03)90372-3

25. U c h i h o r i, Y. et al. Analysis of the calibration results obtained with Liulin-4J spectrometer-dosimeter on protons and heavy ions, Radiation Measurements, 35, 127-134, (2002). doi:10.1016/S1350-4487(01)00286-4

26. G r e e n et al., An empirical approach to the measurement of the cosmic radiation field at jet aircraft altitudes, Adv. Space Res. 36, 9, 1618-1626, 2005.

27. D a c h e v, Ts., B. T o m o v, Yu. M a t v i i c h u k, P. D i m i t r o v, N. B a n k o v, Relativistic Electrons High Doses at International Space Station and Foton M2/M3 Satellites, Adv. Space Res., 1433-1440, 2009. doi:10.1016/j.asr.2009.09.023

28. Ionizing Radiation in our Environment, http://www.who.int/ionizing_radiation/env/en/, March 2011.

29. http://www.faa.gov/data_research/research/med_humanfacs/aeromedical/radiobiology/cari6/

ПРЕГЛЕД НА РЕЗУЛТАТИТЕ ОТ ИЗМЕРВАНЕ НА ЙОНИЗИРАЩИ ЛЪЧЕНИЯ В АТМОСФЕРАТА ПО ДАННИ ОТ ПРИБОРИ, РАЗРАБОТЕНИ В БЪЛГАРИЯ

Ц. Дачев, Б. Томов, Ю. Матвийчук, П. Димитров, Ф. Спурни, О. Плоц, Ю. Учихори, Е. Флукигер, К. Кудела, Е. Бентон

Резюме

Хората са изложени на йонизиращо лъчение през цялото време, и се знае, че то може да предизвика различни вредни биологични ефекти. Следователно е необходимо да се оцени количествено нивото на експозиция от това излъчване, което да е основа за оценка на рисковете за тяхното здраве. Екипажите на космически кораби и самолети са изложени на високи нива космическа радиация от галактически и слънчев произход, както и на вторична радиация, създадена в атмосферата и структурите на превозното средство.

Мониторингът на екипажите на самолети се изисква съгласно препоръките на Международната комисия за радиационна защита (ICRP) (ICRP 1990) и на Директивата на Европейския съюз (ЕС), която въвежда основните ревизирани стандарти за безопасност (ЕС 1997), които включват и експозицията от космическа радиация. Този подход е приет и в други официални документи (NCRP 2002). В този преглед ние представяме резултатите за радиационната обстановка на планински върхове, самолети, балони и ракети, получени с помощта на спектрометри от типа Люлин, които измерват депозираната енергия със силициев диод. Те са разработени в Българска академия на науките (БАН) за целите на радиационния мониторинг на станцията МИР и на Международната космическа станция (МКС). Тези спектрометри-дозиметри са доразвити, калибрирани и използвани от научни колективи от различни страни. Тяхното калибриране е проведено на различни ускорители, включително в CERN във високо-енергийно радиационно поле, което симулира условията на 10 км надморска височина в атмосферата, както и с тежки йони в ускорителя - HIMAC в Чиба, Япония. Дългосрочна база данни е създадена чрез използването на специално разработен батериен прибор на борда на самолети от типа А310-300 на Чешките авиолинии за периода 2001-2009 г. Данните са от 24 сесии, всяка от които по около 2 месеца. Те съдържат повече от 2000 полета (13 500 летателни часа) по маршрути главно над Атлантическия океан. Получените експериментални данни са сравнени с изчислителни модели като CARI и EPCARD. Измерванията на планински върхове са направени с приборите "Люлин-6S", "Люлин-6МВ" и "Люлин-6М", които използват интернет модул за генериране на WEB страница, в която се публикуват онлайн получените енергийни спектри, дозата и потока чрез LAN интерфейс с протоколите HTTP и FTP. Данните са за различни периоди между 2005 и 2011 г. на върховете Юнгфрау (3453 метра над морското равнище) (http://130.92.231.184/); на Ломнички щит (2633 метра над морското равнище) (http://147.213.218.13/) и Мусала (2925 метра над морското равнище) (http://beo-db.inrne.bas.bg/moussala/) в Швейцария, Словакия и България съответно. 4 малки по размер батерийни прибора са използвани при полет на балон над южна Франция през юни 2000 г. и в балон на НАСА над Ню Мексико, САЩ на 11 юни 2005 г. 1 е използван в ракетен експеримент през януари 2008 г.