TECHNICAL DESCRIPTION OF LIULIN-4 TYPE LET SPECTROMETERS (LETS)

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Introduction

The Linear Energy Transfer (LET) spectrometer (LETS) Liulin-4 type main purpose is to measure the specter (in 256 channels) of the deposited energy from primary and secondary particles at the aircraft altitudes, at Low Earth Orbits (LEO), outside of the Earth magnetosphere on the route and on the surface of the planets of Solar system. It sensitivity was proved against neutrons and gamma radiation, which allows monitoring of the natural background radiation also. The LETS is a miniature spectrometer-dosimeter containing: one semiconductor detector, one charge-sensitive preamplifier, 1 or more microcontrollers and a flash memory. Different modifications of LETS use displays and/or Global Positioning System (GPS) receivers. Pulse analysis technique is used for the obtaining of the deposited energy specter, which further is converted to the deposited dose and flux in the silicon detector. The unit is managed by the microcontrollers through specially developed firmware. Plug-in links provide the transmission of the stored on the flash memory data toward the standard Personal Computer (PC). PC is used for the full management of the LETS through standard serial or parallel communication port. On the PC is stored the full data sets and it is used for data visualization and preliminary analysis.

Spectrometer development history

Liulin-4 type spectrometer is a successor of the Bulgarian-Russian dosimeter-radiometer LIULIN [1], which was installed in the working compartment of the MIR space station in 1988. LIULIN measurements were carried out under a wide variety of solar and geomagnetic activity conditions. They provide an excellent opportunity to study effects on the dose-rates and fluxes in the near Earth radiation environment over long time periods, as well as rapid changes, induced by solar proton events and geomagnetic disturbances in the 1989-1994 time frames [2-7].

Main characteristics of Liulin-4 LETS was proved on the Liulin-3M instrument, which was designed together with scientists from Radiation physics office GSFC, NASA [8,9] for continuous monitoring of the radiation environment of the BION-11/12 satellites and on aircrafts. The LIULIN-3M instrument was calibrated by proton fluxes with different energies at the Indiana University Cyclotron Facility in June 1997 and was used for space radiation measurements during commercial aircraft flights [7a,b].

Liulin-4 type Mobile Dosimetry Unit was developed in a cooperation with Dr. R. Beaujean under CONTRACT of 27.09.1996 between STIL-BAS and the Rektorat der Christian-Albrechts-Universitaet zu Kiel on the topic "Dosimetrie im Weltraun", conducted under DARA proposal 50WB9418 from 28.03.1996.

Fig.1. External view of the Liulin-E094 system. One of the Mobile dosimetry Units is seen alone at the right hand side of the system Other 3 units are inside of the Control and Interface Unit (CIU)

Modifications of the LETS for purposes of scientific projects

First use of Liulin-4 type LETS was in the Mobile Radiation Exposure Control System **- Liulin-E094** (Figure 1). It contains 4 active individual dosimeters of Liulin-4 type and worked successfully between May and August 2001 on the board of US Laboratory module of the International Space Station (ISS). The system was a part of the experiment Dosimetric Mapping E094, which was placed in the US Laboratory Module in the composition of the Human Research Facility (HRF). The German (University of Kiel) build two DOSimetric

TELescopes (DOSTEL) and Hungarian build 10 Thermoluminescent Dosimeters and reader (PILLE) are the other 2 instruments included in the experiment Dosimetric Mapping. The Principal Investigator of the experiment was Dr. Guenther Reitz from DLR, Germany. Liulin-E094 was build under contract with DLR and was qualified for space use at DLR and NASA facilities in 1999-2000. Calibrations of the dosimeters was partially performed together with Prof. Josef Lemaire and Prof. Ghislain Gregoire under a Contract between STIL-BAS and Belgian Institute for Space Aeronomy, and Institut Georges Lemaître and the Institut de Physique Nucléaire of the Université Catholique de Louvain (UCL) at the UCL Cyclotron facility in 1999 [10].

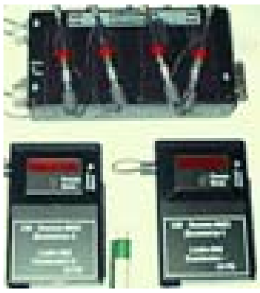


Fig. 2. Two of the Liulin-MKC dosimeters and CIU, which will be operated on Russian segment of ISS for 15 years. Launch is scheduled for 2003

Next use of Liulin-4 type LETS in space is scheduled till the end of 2003. **Liulin-MKC** (Liulin-ISS) is the designation of this devise (Figure 2). It contains 4 spectrometers with displays and CIU and is scheduled to be used for 15 years in the Service Radiation Monitoring System of the Russian segment of ISS. Following information is able to be shown on the display: - Current dose in (μGy/hour); - Current event rate (Flux) (cm^{-2} s^{-1});- Accumulated from the "Switch ON" dose (μGy). The battery operation time of the spectrometers is about 7 days.

R3D-B spectrometer (82x57x25 mm) with 256 channels LETS spectrometer and 4 channels UV spectrometer (Figure 3). These type spectrometers were specially designed for short-term monitoring of the FOTON-1M satellite radiation environment inside of the ESA BIOPAN facilities experiment. The total mass is 0.128 kg. The operation time of the spectrometers is about 15 days for fulfilling of the total 1.0 MB flash memory with 30 sec resolution. The qualification tests of the spectrometer were performed in ESTEC in 2002. R3D-B was unsuccessfully launched on FOTON-1M satellite on 15 October 2002. It is expected the experiment with BIOPAN facility to be launched again in 2004 and 2005.

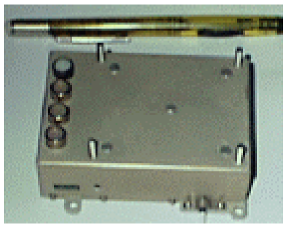


Fig. 3. External view of R3D-B spectrometer.

Next use of this type of spectrometers is the **R3D** instrument [10a,b] (76x76x35 mm) with 256 channels LETS spectrometer and 4 channels UV spectrometer (Figure 4.). It was specially designed for more than one year monitoring of the ISS Columbus module radiation environment inside of the ESA facilities EXPOSE. R3D instrument is a part of the experiment SPORES, which is leaded by Dr. Gerda Horneck, Institute of aerospace medicine, DLR, Germany. It is developed in cooperation with Prof. Dr. Donat-P. Häder, Friedrich-Alexander Universität, Institut für Botanik und Pharmazeutische Biologieis, Erlangen and with Wolfram Saedtler from Kayser Thrade GmbH, Germany. R3D total mass is 0.150 kg. The spectrometer communicates with the EXPOSE facilities through RS422 interface and will transmit the measured data with 30 sec resolution to the Earth. The flight model of the spectrometer was delivered to Kayser Thrade GmbH in the middle of June 2003 and is going trough qualification tests together with the EXPOSE facility. The EXPOSE experiment is expected to be launched toward ISS in 2004/2005.

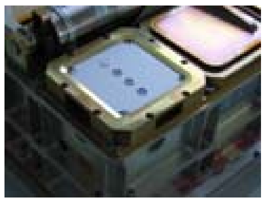


Fig. 4. R3D view as mounted inside of EXPOSE facility

Calibrations of LETS of different modifications on protons, alphas and heavy ions were performed under the cooperation with Dr. K. Fujitaka and Dr. Yukio Uchihori from National Institute of Radiological Sciences, Chiba, Japan [11,12].

Calibrations of LETS of different modifications on gamma and neutron sources and on CERN reference field were performed under the cooperation with Prof. F. Spurny from Nuclear Physics Institute of Academy of Sciences of Czech Republic [15].

Commercially available LETS modifications

Up to the middle of 2003 different types of LETS has been designed:

Fig. 5. Picture of the Small size LETS without display.

- Small size (100x64x24 mm) without display. The total mass is 0.23 kg including 0.08 kg SONY NP-F550 rechargeable Li-ion battery pack. 4 of this type spectrometers (Figure 5) has been successfully used in the US Laboratory module of International Space Station (ISS) by the Second crew in the period May-August 2001 [13]. The operation time of the spectrometers is about 5 days fulfilling usually about 0.3 MB of the total 0.5 MB flash memory with 30 sec resolution. Further development of the spectrometer extends the operation time up to 7 days. One of the spectrometers of this type perform 23 flights on the NASA ER-2 aircraft during 2000-2002 time frame [14];

Fig. 6. Picture of the Small size LETS with display.

- Small size (100x64x24 mm) with 8 characters 5x7 alphanumeric LED display (Figure 6). The total mass is 0.25 kg including 0.08 kg SONY NP-F550 rechargeable Li-ion battery pack.). 4 of these type spectrometers in the configuration of Liulin-MKC system (Fig. 2.) are scheduled to be used for 15 years in the Service Radiation Monitoring System of the Russian segment of ISS. Following information is able to be shown on the display: - Current dose in (μGy/hour); - Current event rate (Flux) (cm^{-2} s^{-1});- Accumulated from the “Switch ON” dose μGy. The operation time of the spectrometer is about 7 days.

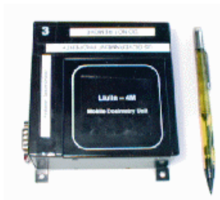


Fig. 7. Picture of the large size LETS without display.

- Large size (100x100x50 mm) without display (Figure 7). These type spectrometers were specially designed for long-term monitoring of the aircrafts radiation environment (Figure 3.). The total mass is 0.33 kg including 2x0.09 kg SAFT LS-33600 Li primary batteries.) The operation time of the spectrometer is more than 100 days fulfilling usually about 0.36 MB of the total 0.5 MB flash memory with 480 sec resolution. One of these type spectrometers works successfully 5x2 months on CSA A310-300 aircraft [15]. Most remarkable of it work there is the measurements during the Ground Level Event -60 (GLE) on the route Prague-New York on 15.04.2001. For more details please see Figures 25, 26 and 27.

Fig. 8. Picture of the large size LETS without display.

- Large size (90x85x53 mm) with for monitoring of the aircrafts radiation environment (Figure 8). The total mass is 0.29 kg including 1 rechargeable Sony Li-ion battery. The operation time of the spectrometer is more than 30 days. It use 1 MB flash memory
- Liulin-4S spectrometer (100x85x25 mm) with 256 channels LETS spectrometer and GPS receiver (Figure 9). These type spectrometers were specially designed for the IBERIA airlines space radiation study program. The spectrometer is designed for multi-session use with the same initialization parameters as the first one. Rockwell’s Zodiac Global Positioning System receiver is used for processing the signals from all visible GPS satellites for 3D geographical and time positioning of the measurements. The Zodiac receiver provides an output timing pulse that is synchronized to one second with UTC (Universal Time Coordinated) boundaries. All measurements are organized with UTC. The GPS antenna is outside of Liulin-4S on a 5 m long cable. The power supply of Liulin-4S is performed with a DC/DC converter, which is electrically insulated from the internal signal ground and from Liulin-4S external box, which meet JAA requirements for installation of any equipment in an aircraft. On Figure 10 are presented 2 altitudinal

Fig. 9. External view of Liulin-4S. Rechargeable battery package is at the top of figure. Gray box is the GPS active antenna..

profiles, obtained with GPS receiver in Liulin-4S during a travel by car toward Stara Zagora town and back. The statistics of the measured altitudes from Sofia to Stara Zagora shows the following: 402 measured points; 2.7 m average altitude error; 1.5 m standard deviation; 1.8 m minimum error; 26.6 m maximum error, obtained when a road tunnel was crossed.

The team is ready to perform new developments of Liulin-4 type spectrometers under the specific requirements of the customers.

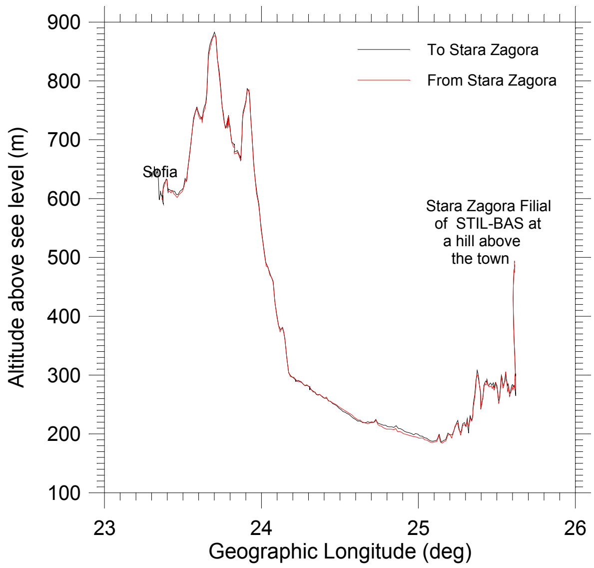


Fig. 10. Altitudinal profiles of the car routes from Sofia to Stara Zagora town and back obtained with the GPS receiver and processed by Liulin-4S

Description of the (LETS)

The LETS is designed as a handy spectrometer-dosimeter for continuous monitoring of the radiation environment in different radiation fields. After switching on, the LETS starts to measure in 256 channels the spectrum of the deposited energy used further to calculate the dose and the flux of particles in the silicon detector. The exposition time of one spectrum is variable in the interval 10 sec - 3539 sec. After finishing the first measurement cycle the spectra, accumulated dose and flux are stored in the flash memory. Each next measurement results are stored in a different place of the memory, which later is used for recalculating of the time of the measurement. After connection of the LETS with PC all data accumulated are transmitted to it.

The LETS contains: one semiconductor detector with 2 cm^2 area and 0.3 mm thickness, one low noise hybrid charge-sensitive preamplifier A225 type of AMPTEK inc.; a fast 12 channel ADC; 2 or 3 microcontrollers and flash memory of 0.5 or 1.0 MB capacity. Pulse high analysis technique is used for measurement of the energy losses in the detector. The unit is managed by 2 microcontrollers through specially developed software. A block schema of portable spectrometer-dosimeter in the LETS is presented in Figure 11.

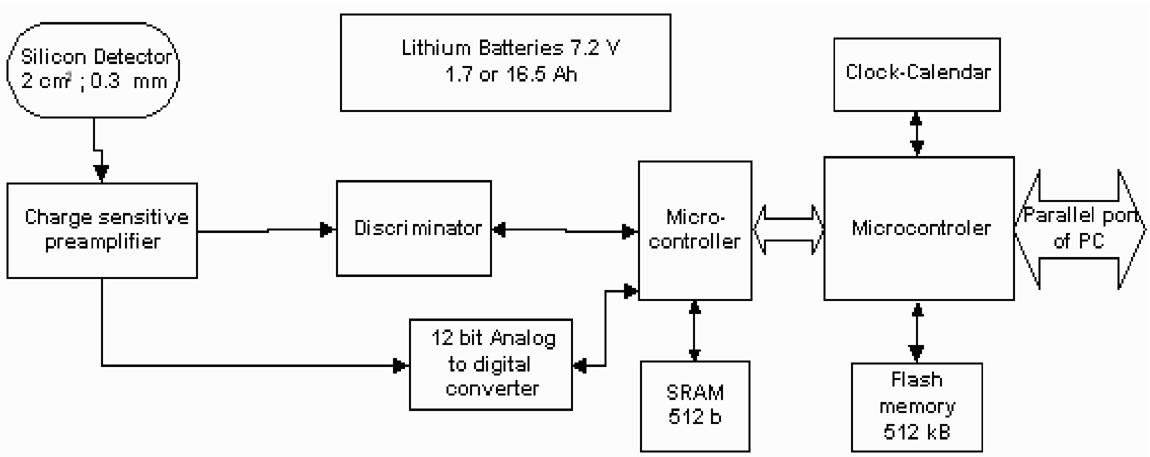


Figure 11. Block-scheme of the LETS

The main measurement unit in the LETS is the amplitude of the pulse after the preamplifier, which is proportional by a factor of 240 mV/MeV to the energy loss in the detector and respectively to the dose and LET. By the 12 bit ADC these amplitudes are digitized and organized in a 256-channel spectrum using only the oldest 8 bits of the ADC. The spectrum together with information for the real time is saved in the flash memory of the instrument. The capacity of the memory is 0.5 MB, which is enough for storage of 8 days non-stop measurements with 30 sec exposition time ore 80 days non-stop measurements with 600 sec exposition time.

The following method for calculations of the dose is used: The dose D [Gy] by definition is one Joule deposited in 1kg or:

D = K.Sum(EL_I*i)$_{30\ sec}$/MD,

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.

The LETS operate in 3 modes: Working mode, Mode of Transferring the data from the flash memory to PC and Mode of initialization of the unit:

- In the Working mode the instrument is performed under the software in the microcontrollers. The operational time of the instrument depends on the lifetime of the batteries and on the rate of the memory fills up. The working mode is switched OFF automatically when either the memory is totally filled up or the supply voltage is falling below 6.0 V DC. When the supply voltage of the battery falls down then 6.0 V the process of measurements stops and the LETS status indicator start to flash each second, signalizing the necessity for replacement of the batteries.
- In the mode of data transferring the instrument is switched on by special command when it is connected to PC parallel interface after the end of the experiments. The mode allows the transfer of the accumulated in the flash memory data to the PC.
- In the mode of initialization is switched on by special command when it is connected to PC parallel interface before the experiments. The mode allows the user to select the necessary exposition time of the LETS. In this mode the transfer of the real time data from the PC toward the LETSs is performed.

When LETS is connected to PC it takes from the PC system information block the real calendar and clock time. Clock-calendar data are used further to evaluate the measurements. Time accuracy of the intervals in the LETS is about 10^{-5} s. Data accumulated in the flash memory of LETS are transmitted to the PC by the parallel interface connection using a specially developed protocol. The Liulin software product (Liulin-4.exe) is developed in "WIN95/98NT" environment. At the PC it creates automatically the subdirectory "Liulin_4 Data" in the directory in which "Liulin-4.exe" is located. In the subdirectory "Liulin_4 Data" four types of files are automatically created. The binary file of LETS is named automatically and contains in the name YYMMDDHHmm.L01, where "YYMMDDHHmm" is the date and time of the first measurements with the LETS. This file contains the rough binary data and are for permanent storage of data from the instrument, because of the minimal volume of the file. Three additional ASCII files are created automatically for each binary file. The names of these additional ASCII files contain the same "YYMMDDHHmm" string as the binary files. The files with extensions of type "D01" and "S01" "Y01" contains the "D"ose, "S"pectrum and "Y" (pure spectrum) data from the LETS.

The first 3 rows of the dose (*.D01) file looks as follows:

```
MDU-01  EXPOSITION = 300[Sec]
DD/MM/YY hh:mm:ss  DOSE = x.xx[uGy/h]  FLUX = x.xx[p/cm2.Sec]
07/10/02 19:22:00 0.144359    0.0716667   129   43
```

where the meaning of the columns is: **Date**, **Time**, **Dose** (uGy/hour), **Flux** (cm^{-2} s^{-1}), **Sum(eventN*ChanellN), Sum of events in all channels**

The first 4 rows of the full spectrum (*.S01) file looks as follows:

```
MDU-01  EXPOSITION: 300[Sec]
DD/MM/YY hh:mm:ss  DOSE = x.xx[uGy/h]  FLUX = x.xx[p/cm2.Sec]
0 15 9 3 5 5 3 2 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0
07/10/02 19:22:00 DOSE = 0.144359   FLUX = 0.0716667  129   43
```

where the 256 columns contains the number of event in each channel and the row after contains the same information as in dose file.

The first 2 rows of the spectrum (*.Y01) file looks as follows:

```
MDU-01  EXPOSITION: 300[Sec]
0 15 9 3 5 5 3 2 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0

where the 256 columns contains the number of event in each channel.

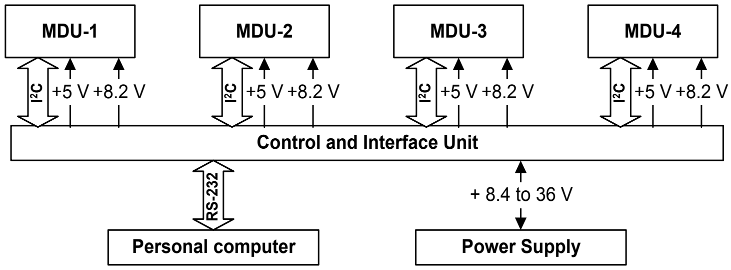


Fig. 12. Place and functions of the Control and Interface Unit.

Description of the Control and Interface Unit

The Control and Interface Unit (CIU) is a miniature interface between the external power supply, PC and LETS (see Figure 12).

Two different types of CIU have been developed – CIU (Figure 13.) with full operational support of LETS including charging of the accumulators and simple CIU (Figure 14.), which provides only connection with the parallel port of the PC.

Power supply passes to the CIU DC current with the voltage in the interval +8.4 to 36 V DC (see Figure 5). CIU is connected to PC by standard interface RS-232 type. CIU contains microcontroller, clock-calendar, DC/DC converter (20 IMX 15-12-12-7 type) from +28 V to 2x12 V 2x0.65 A, 4 chargers for Li-ion batteries (LT1512 type), one serial communication port of RS-232 type, 4 red LEDs indicating the charging process and 4 yellow LEDs indicating the transfer data process.

Fig. 13. External view of the

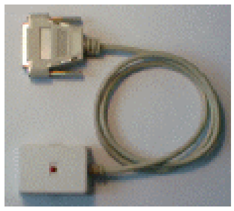
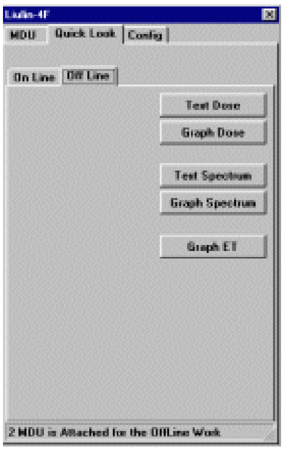
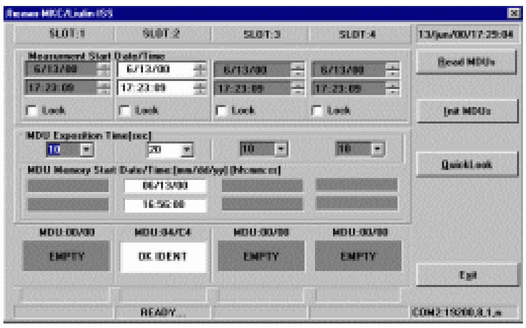


Fig. 14. External view of Simple CIU

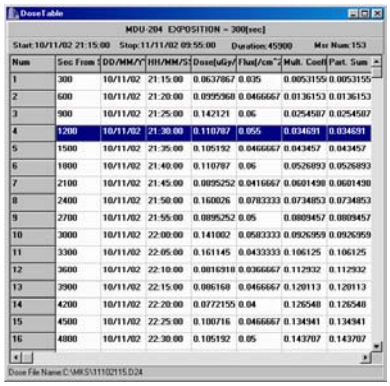
The initialization of the Control and Interface Unit is performed automatically when it is connected to the power supply. The success of the internal test is indicated by subsequent turn off of the yellow lamps on CIU. Further CIU continue to work independently till the first connection to the PC. When CIU is connected to PC it takes from the PC



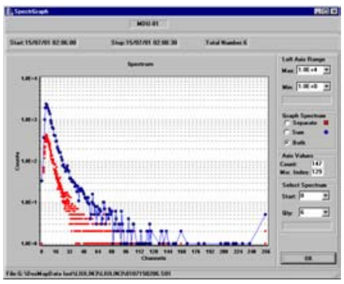
Simple CIU screenshot



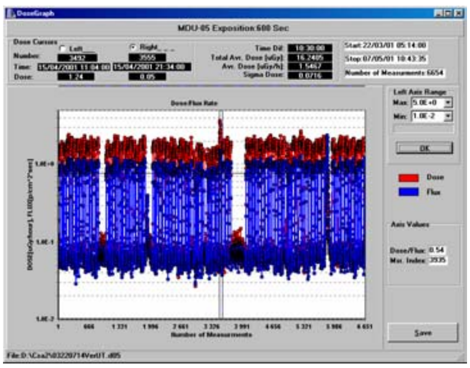
4 slot CIU screenshot



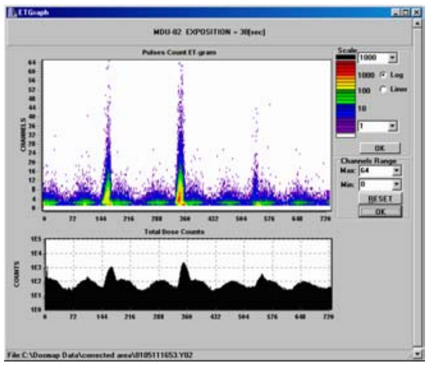
Dose listing



Spectrum visualization for the SAA spectra obtained on ISS in 2001



Dose visualization for a CSA aircraft flight. The maximum seen in the middle corresponds to the GLE-60 event



Color-coded presentation of the spectra along the orbit of the ISS system information block the real calendar and clock time.

The Liulin software product (Liulin-4.exe) contains a Quick look part, which is used for the express analysis of the results. The program includes subprograms for data listing and data visualizations. Different initialization screenshots and data visualization options are shown on the previous 6 figures.

Calibrations of LETS

LETS were exposed in reference radiation fields. The results obtained at some photon sources are presented in Figure 15. Not only experimental but also theoretical event spectra in the semiconductor are presented for ^{137}Cs and ^{60}Co photons. They were calculated by means of EGS 4-transport code and one can see that the agreement of both spectra is rather satisfactory [15].

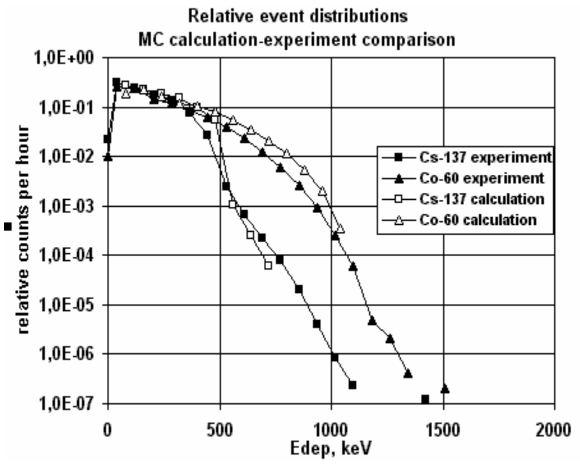


Fig. 15. Event spectra obtained in some photon beams.

The spectrometer was also exposed at some neutron sources. Rather large differences in the event spectra were observed (Figure 16.). While for photons the maximum impulsion's height is about 1 MeV, for neutrons it reaches up to 10 MeV [15]. It could permit to distinguish photon and neutron induced events in other radiation fields.

Tests with LETS units were performed on protons and heavy ions [16,17] and good agreement was found between the measured and predicted by the GEANT code simulations spectra.

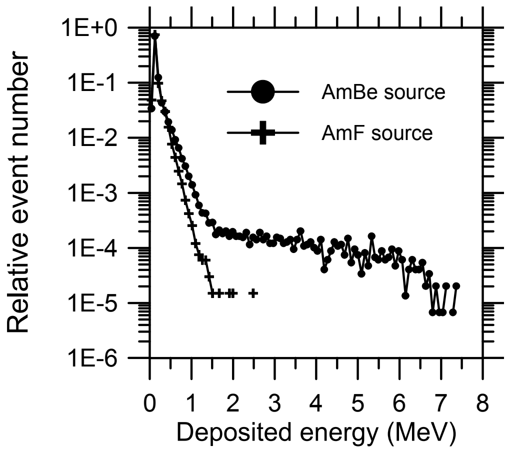


Fig. 16. Experimental spectra obtained by irradiation of LETS with two different neutron sources.

The obtained results with 40 MeV proton beam is shown on Figure 17 for 4 different incidence angles toward the detector surface 0°, 45°, 60° and 75°. In the lower panel of the figure the experimental Liulin-4 data are plotted, while the GEANT 4.0 predictions are shown in the upper panel. The dashed vertical lines shows the positions of the predicted by GEANT maximums. It is well seen that the positions of the predicted and measured spectra maximum coincide with accuracy les than 0.2 MeV [5]. On Figure 18 the "Bethe-Bloch" behavior of Liulin experimental data at normal incidence (pluses) versus energy is shown. The squares refer to Ziegler and Williamson estimations while the continuous line is the prediction of GEANT 3.21 [4].

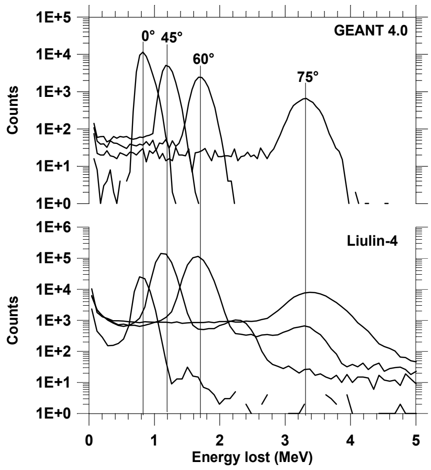


Fig. 17. Liulin and GEANT 4.0 comparisons for 40 MeV proton beam.

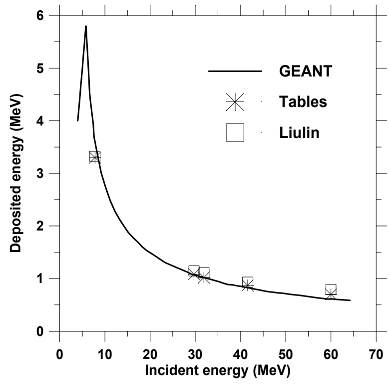


Fig. 18. "Bethe-Bloch" behavior of Liulin experimental data at normal incidence.

The experimental setup at the HIMAC, Japan irradiation facility was as follow: The 500 MeV/u Fe ions beam delivered by the HIMAC exit passes first through the target of different thicknesses and materials located at 1 cm distance from the exit. Next the beam passes of 100 cm air before the entrance of the LETS sensor. The LETS is fixed on a computer X-Y and rotating table. A removable ZnS plate before the real experiments tests the uniformity of the beam. Plastic scintillation counter was used to measure the count rate of the beam.

When the spectrometer was irradiated with iron 500 MeV/u ions at 0° offset from the beam for 30 seconds the major amount of counts are delivered to first 3 channels and in the last channel of the spectra. The deposited energy in the last channel is greater than 20.83 MeV and can be attributed to the primary iron ions. Mainly secondary light ions and protons populate the amount of channels between 255 and 4, while mainly protons and electrons fill the first 3 channels.

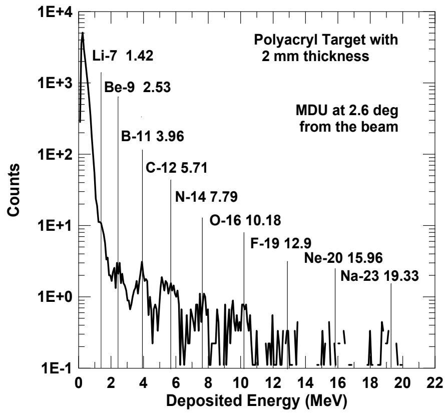


Fig. 19. Example of the fragmentation behind of 2 mm polyacryl target.

On Figure 19 are presented the results obtained by the irradiation of Liulin spectrometer placed at 2.6° from the main beam for 30 seconds. The spectra presented at Figure 9 is populated by secondary particles, produced by the interaction of the primary 500 MeV/u iron ions with the polyacryl target with 2 mm thickness. Lithium, Beryllium Boron, Carbon, Nitrogen, Oxygen, Fluorine, Neon and Sodium ions was recognized in the spectra using the Kanai calculations [18]. Average deposited energies of the light ions were calculated analytically. It was assumed that every ion underwent energy loss only through ionization and that there was no energy loss from nuclear interactions in the acrylic plate. We also assumed that all fragment ions were produced at the center of the thickness of the acrylic plate. The estimated deposited energies of the projectile fragments are indicated in Fig. 19 by vertical lines. For neon or heavier ions there was a slight disagreement between the measurement and the estimates, while for lighter ions measurement and calculation were in good agreement.

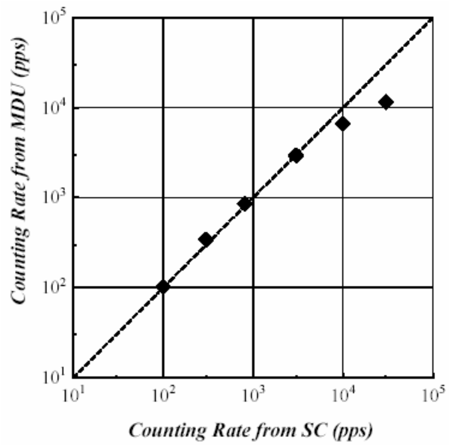


Fig. 20. Efficiency of count rate data acquisition at high counts rates.

The efficiency of the count rate (flux) acquisition was also studied [17]. After the beam intensity was tuned against count rate of a scintillation counter, the LETS was irradiated and the detected numbers of charged particles were counted. In Figure 20, the horizontal axis is the scintillator count rate used as a reference and the vertical axis is the count rate of the LETS. When the rate by the LETS was not proportional to the reference count rate due to dead time of the data acquisition circuitry in the LETS. This reference count rate was over about 3000 particles per second, the count means that as along as the charged particle flux in the space environment remains below 3000 cps, the LETS is capable of measuring the flux with full efficiency.

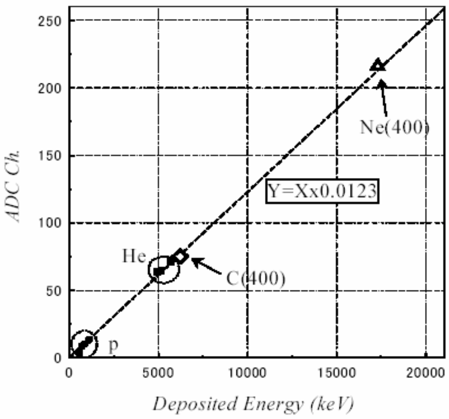


Fig. 21. All data for irradiation at 0° incident angle are shown. Data are in good agreement with the formula ADC=Ex0.0123, which was obtained from the cyclotron experiments.

Figure 21 summarize all available results, obtained by Dr. Uchihori [17] during the calibrations in NIRS, Japan. At the lover left corner points represents the obtained results with protons, while in the middle helium (100 MeV/n) and carbon (400 MeV/n) ions energy deposition are plotted. The last point in the upper right corner is from neon ions with 400 MeV/n energy. The dashed line represents the position of the energy depositions obtained during the proton calibrations, which is very close to the predicted ADC=Ex0.012288.

LETS units have been tested since the spring 2000 during three calibrations runs in the CERN-EC high-energy reference field behind the concrete shield [19]. It should be stressed that in this case the spectrum was still much larger than in the case of neutron sources, reaching the highest values of the energy deposition above 20 MeV. It was found that the signal per monitor unit decreases in low E_{dep} region with increasing intensity, due to muon background [19]. For high E_{dep} events, it is independent of the intensity given by monitor units. It is very important for the interpretation of the data measured in reference and similar fields.

As far as the values of dose calculated from the spectra are concerned, they were in very good agreement with the reference values for ^{60}Co photons, the value obtained for ^{137}Cs photons was about 8 % lower than the reference one. In CERN reference field, the dose calculated for low E_{dep} region were about 30 % lower than values measured with other standard low LET measuring instruments (RSS 112 chamber, TLD's, etc.). We have observed the same behaviour also for individual electronic dosimeters based on Si-diode and taken it into account for the interpretation of these detector's readings.

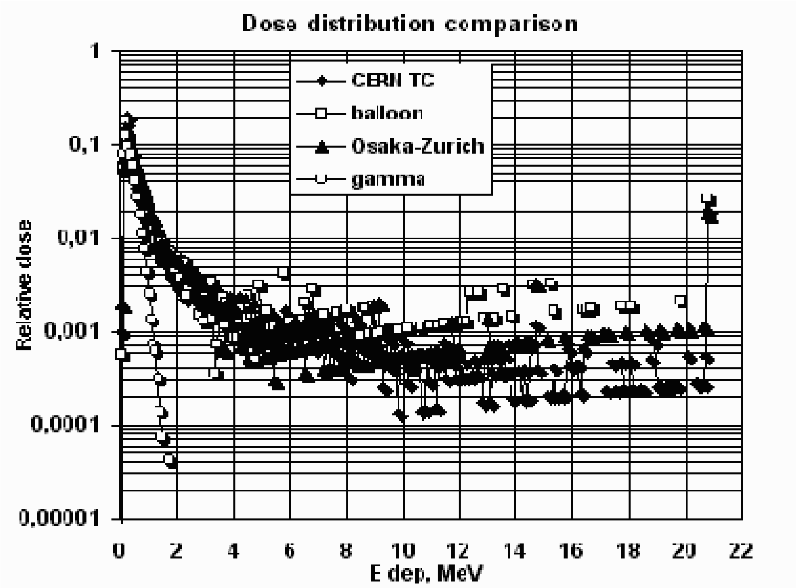


Fig. 22. Comparison of dose spectral distributions for 4 different radiation fields: gamma, CERN TC, balloon (about 30 km altitude) and Osaka-Zurich flight at about 11.7 km.

The spectra registered at CERN reference field are very similar to the spectra registered on the aircraft and/or balloon (see Figure 22.). To interpret the data measured on aircraft board (D(Si)), we decided to use CERN reference field results. The dose in Si measured in low E_{dep} region was supposed to represent the contribution of low LET radiation, the dose in high E_{dep} region that of high LET component (neutrons). Taking into account reference fields values for these components [19], D(Si) measured on board was recalculated to obtain apparent H*(10) values.

As an example for individual flights, the results obtained in the case of CSA flights from Prague to

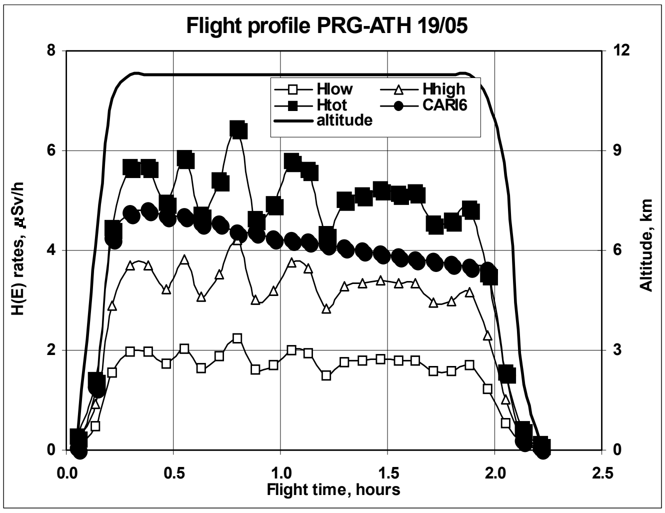


Fig. 23. E Flight profiles Prague-Athens.

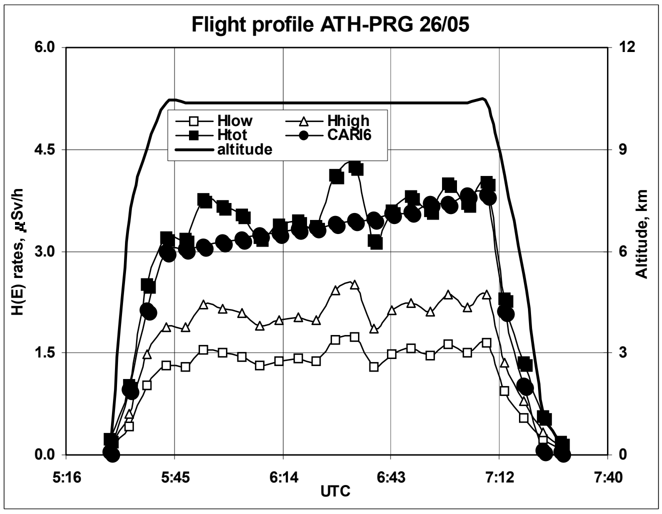


Fig. 24. Flight profiles Athens -Prague

Athens and return are presented in Figures 23. and 24. H_{low} represents doses obtained in the low LET region, H_{high} doses obtained in the high LET region and H_{tot} shows the sum of them. Obtained H_{tot} is compared wit the CARI-6 predictions and a relatively good agreement is obtained.

Aircraft flight results

Since the April 2000, one LETS spectrometer has been used during more than 50 individual and five long-term exposures, about 1200 hours each, with about 540 flights in total. All necessary flight parameters were acquired from colleagues of Czech Airlines, that permitted to calculate the effective dose E on board by means of CARI 6 and EPCARD codes and compare them with the apparent H*(10) values obtained as mentioned above [15]. The results obtained up to now for integral values of dosimetric quantities are presented in the Table 1.

		Flight period during 2001 year			
		22/03-07/05	30/05-24/07	29/08-16/10	25/10-10/12
CARI6 E, mSv	total	2.68	3.78	2.60	1.88
EPCARD3.0 $H^*(10)$ mSv	neutrons	1.57	2.12	1.45	1.00
	others	1.08	1.40	1.05	0.72
	total	2.68	3.52	2.50	1.72
EPCARD3.0 E-ISO mSv	neutrons	1.34	1.82	1.24	0.85
	others	1.77	2.39	1.70	1.17
	total	3.11	4.16	2.94	2.02
Liulin-MDU H_{app} mSv	neutrons	1.54	2.29	1.55	1.07
	others	1.14	1.54	1.04	0.72
	total	2.65	3.83	2.59	1.78

Table 1. CSA aircraft (A310-300) long-term exposures 2001 – comparison of calculated and MDU results treated using CERN calibration.

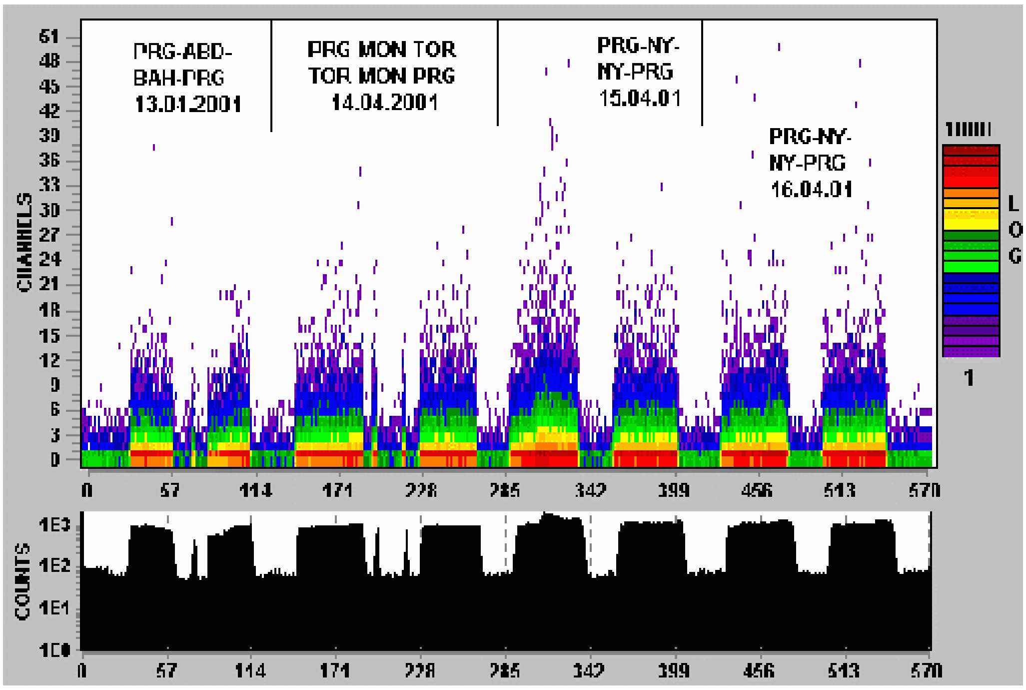


Fig. 25. Color coded presentation of the spectra for 4 selected roundtrip flights on 13, 14, 15 and 16th of April 2001 The effect of GLE-60 event is well seen on the spectra with numbers from 285 to 342.

Figure 25 presents in 2 panels example of the data obtained between 13th and 16th of April 2001. The lover panel in logarithmic scale shows with heavy black bars the total number of counts in each spectrum for each of the 10 minutes intervals, which is proportional to the dose. The lover levels correspond to the natural background radiation encountered by the instrument at the airports. The upper levels show the counts at the cruise altitude of the aircraft. The upper panel of Figure 25 is a color-coded presentation of the instrument spectra in the range from channel number 1 up to channel number 51. This is a representative selection of the 256 channels spectra because in the range from 51st channel up to the 255th no counts are seen. Only in the 256th channel corresponding to energy depositions higher than 20.8 MeV sporadic counts at the cruise altitude are observed. The logarithmic color bar is in the range from 1 to 1000 counts per channel.

It is well seen the differences in the flight profiles for the 4 different routes Prague-Abu Dhabi and back on 13.04.2001, Prague-Montreal-Toronto and back on 14.04.2001 and Prague-New York and back on 15.04.2001 and 16.04.2001. For the route Prague - Abu Dhabi the doses respectively the numbers of counts and specter length decreases permanently, because of the increase shielding by the Earth magnetic field. For the routes Prague - New York and Prague - Montreal, which are at similar magnetic latitudes the flight profiles are similar. It is well-seen increase of the doses at the end of the flight connected with the aircraft altitude increase.

The Ground Level Event number 60 (GLE60) on 15th of April response is observed between spectra number 285 and 342 on the first route Prague-New York and back. Except the total dose counts increase it is seen increase in the length of the spectra. The number of the events in the second channel, where the maximum of spectrum is, increases too.

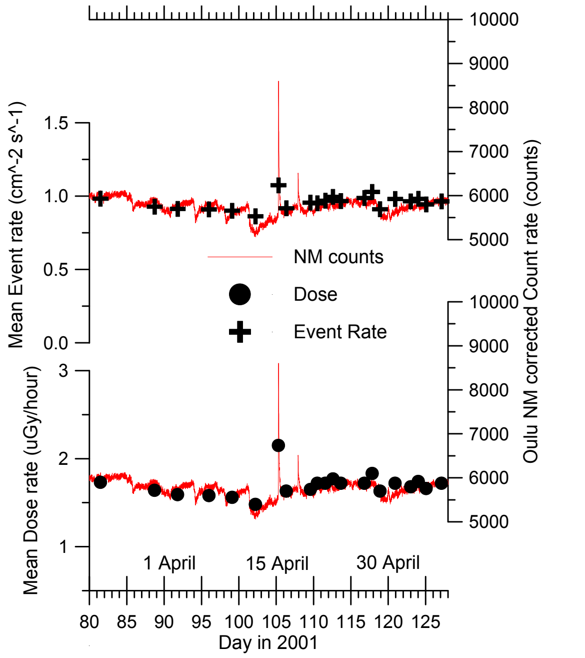


Fig. 26. Long-term variations of dose and event rate obtained with LETS in comparison with Oulu neutron monitor data.

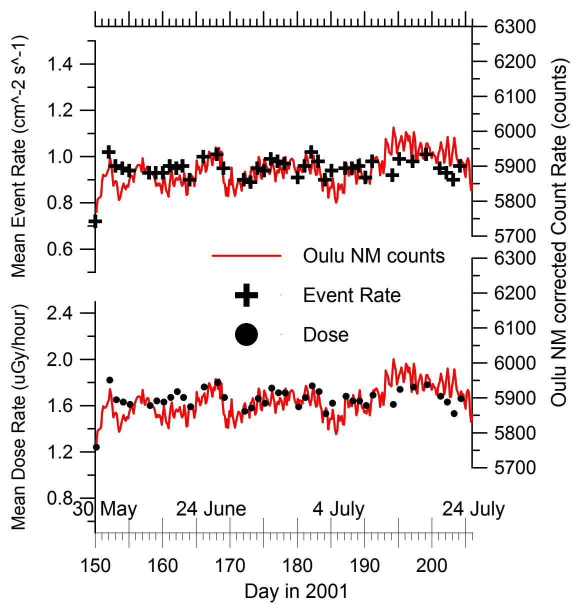


Fig. 27. Same as Fig.19 for another time interval.

The long-term variations of the Si dose and the Event rate for the flight between 23.03.2001 and 07.05.2001 are presented on Figure 26. Oulu neutron monitor data are used for the reference variations in the galactic cosmic rays. From Figure 26 it is well seen that measured onboard mean data at the cruise altitude for the flights from Prague to New York and the galactic cosmic rays variations correlate in great details. The large minimums and peaks seen in the middle of the figure correspond to the forbush decrease and two solar cosmic rays events in April 2001.

Figure 27 presents in similar way the long-term correlation between Oulu neutron monitor data and the onboard measurements for the flight performed between May 30 and July 25 2001.

ISS results

The Mobile Radiation Exposure Control System - Liulin-E094 contains 4 LETS and worked successfully between May and August 2001 on the board of US Laboratory module of the International Space Station (ISS). Their application is highly recommended by the ISS Multilateral Radiation Health Working Group. The main purpose of Liulin-E094 is to be monitored simultaneously the doses and fluxes at four independent places of the station. The system is a part of the experiment DOSMAP E094, which was placed in the US Laboratory Module in the composition of the Human Research Facility (HRF) [http://hrf.jsc.nasa.gov/science/e094.htm]. Dr. Guenther Reitz from DLR was PI of the DOSMAP experiment.

The German (University of Kiel) build two DOSimetric TELescopes (DOSTEL) and Hungarian build 10 Thermoluminescent Dosimeters and reader (PILLE) are the other 2 instruments included in the experiment Dosimetric Mapping. The Principal Investigator of the experiment was Dr. Guenther Reitz from DLR, Germany. All units of the experiment were connected trough the Power Box service unit, build by University of Kiel, with the HRF laptop PC and power line of the station. The dosimetry information from E094 experiment was transmitted by RS-232 to the HRF PC hard disc drive. Part of it was passed to the Earth.

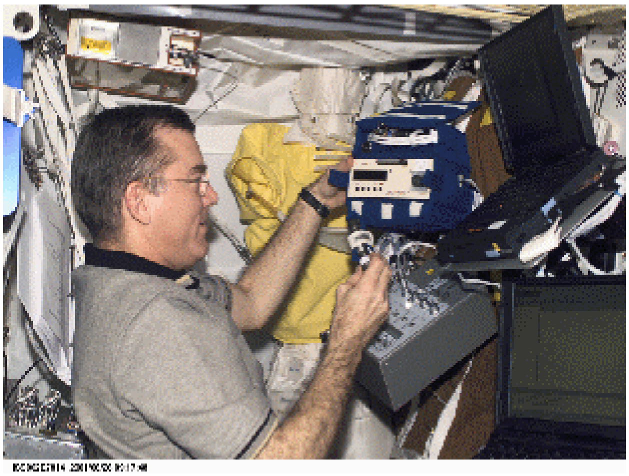


Figure 28. American astronaut James Voss working with Dosimetric mapping experiment on 26.06.2001.

The experiment with the Dosimetric mapping system has been performed on the board of the International Space Station by the Second crew including: Yury Usachev – commander and two flight engineers James Voss and Susan Helms. American astronaut James Voss was directly engaged in the work with the experiment (see Figure 28.). The first run of the Liulin-E094 system occurred on 11 May, 2001, while the last one was on 21 July 2001. Totally 20 runs of the MDUs was performed, covering practically all the period. 4,5 MB rough compressed information was received by each MDU.

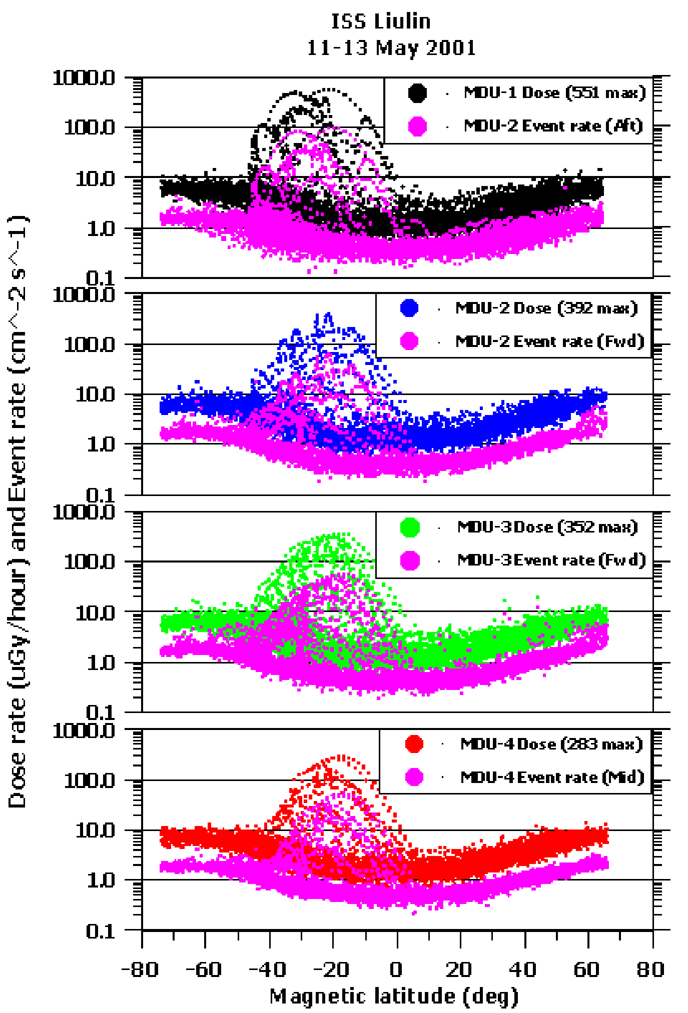


Figure 29. Intercomparison of the Liulin-E094 data obtained in the period 11-13 May 2001.

On Figure 29 are presented data obtained by the 4 different LETS, which was named in the experiment with the acronym MDU – Mobile dosimetry Unit [20]. For the X coordinate is used the geomagnetic latitude, while in the Y coordinate the dose and event rate are plotted. It is seen that the dose and event rate reached the minimal values close to the magnetic equator with values very similar to those obtained on aircrafts. The maximums of the dose and event rate seen in the Southern hemisphere are obtained in the region of the South Atlantic Anomaly (SAA). Values in the SAA are different for the different MDUs because of different shielding and orientation of the station. Maximum values are seen in MDU-1 of 551 µGy/hour, which is connected with the East-West asymmetry in the region of SAA. MDU-1 is located at the aft side of Node-1 and is measuring the more dense proton flux coming from west and above the ISS. The Galactic cosmic ray (GCR) component of the ISS radiation environment is seen clearly as heavy populated lines with minimums at the magnetic equator and maximums at high latitudes in both hemispheres. As it is expected the observed values in different MDUs are very similar, because high penetrating capability of GCR.

Specifications of LETS

Parametesr		
Detector Thiknes DT [mm]	0.300	
Detector area DA [cm $^{-2}$]	2	
Detector mass DM [kg]	0.0001398	
Amplifier Sensitivity AS [V/MeV]	0.24	
Number of ADC channels N	1024	
Threshold level TL [keV]	8	
A225 Time resolution TR [μs]	10	
Ranges	**Range min**	**Range max**
Pulse height PH analysis [V]	0.00488	5.0
Energy loss EL [MeV]	0.02034	20.83333
LET range [keV μ^{-1}]	0.06781	69.44444
Dose range D [Gy]	2.3314E-11	0.001564
Dose Rate DR range [Gy hour^{-1}]	2.7977E-09	0.187745
Flux range FR [cm^{-2} s^{-1}]	0.01	5000
LET range [MeV cm^2 g^{-1}]	0.29105	298.0448
.Lowest possible LET at 8 keV threshold level [MeV cm^2 g^{-1}]	0.11444	
Charge deposition CD [fC] (1 MeV in Si = 44 fC)	0.89518	916.6666
Temperature range	-40^{o}C	+60^{o}C
Power consumption: at normal operation	6.5 mA from 6.5 to 10 V DC	
Power consumption during flash memory cleaning	38 mA	

Space Qualification and Certification of the LETS instruments

Historically 8 space-qualified instruments has been build and successfully operated by the same scientific group of STIL-BAS:

- ANEPE - low energy analyzer worked on board of Intercosmos-Bulgaria-1300 satellite during the whole lifetime (4 years) of the satellite;
- DANI - fast satellite potential analyzer worked on the Russian APEX satellite;
- DANI-S - low energy analyzer worked on board of MAGION-2 subsatellite;
- LIULIN dosimeter-radiometer on MIR space station worked almost 6 years in space. The detector unit of the system was brought back to the Earth in 1995 and successfully tested again at Brookhaven National Laboratory Alternating Gradient Synchrotron (AGS) in cooperation with Dr. Jack Miller [21];
- Liulin-E094 instrument with 4 LETS was qualified for space use in the composition of the HRF DOSMAP-E094 experiment in 1999-2000. The EMC and vibration tests and certificates was issued in August 1999 by Industrieanlagen Betriebsgessellschaft mbH, 85521 Ottobrunn, Germany. The burn in test was performed in DLR, Cologne, Germany. The off-gassing test was performed by Materials Physics and Chemistry Section, Materials and Processes Division, ESTEC, Nordvijk, Nederland;
- Liulin-MKC instrument with 4 LETS with displays was certified by Institute of Biomedical Problems and ROSAVIACOSMOS, Moscow, Russia;
- R3D-B instrument was qualified in 2002 at ESTEC, Nordvijk, Nederland.
- R3D instrument is under qualification procedure at Kayser Thrade GmbH, germany (summer of 2003).

<u>Who is using Liulin type spectrometers and where?</u>-Dr. G. Reitz, DLR, Institute fuer Luft-und Raumfahrtmedizin, Cologne, Germany - 4 Cigarettes box size LETS and 4 slot CIU used in the Experiment "Dosimetric Mapping", May-August, 2001 on the International Space Station. It is expected use of the instrument on the Columbus module of ISS;

-Dr. E.G. Stassinopoulos, Goddard Space Flight Center, NASA, USA - 2 large LETSs and simple CIU, 4 Cigarettes box size LETS and 4 slot CIU used for characterization of radiation field at commercial air flights and at Antarctic balloons;

-Dr. K. Fujitaka and Dr. Y. Uchihori, National Institute of Radiological Sciences-STA, Chiba, Japan - 6 Cigarettes box size LETS, 4 slot CIU and Simple CIU, 4 large size LETS. One of them used for 23 ER-2 flights in period 2000-2002, 2 large size LETS with rechargeable SONY Li-ion battery;

-Prof. F. Spurny, Nuclear Physics Institute, Czech AS, Praha, CR - 2 large MDUs and 2 Cigarettes box size LETS and Simple CIU used for about 5x2 months flights on CSA A310-300 aircraft;

-Dr. V. Petrov and Dr. V. Shurshakov, Institute of Biomedical Problems, Moscow, Russia - 6 Cigarettes box size MDUs and 4 slot CIU will be used in the Service Radioprotection System on the Russian segment of the International Space Station for 15 years starting from 2003;

-Dr. J.-F. Bottollier, Institut de Protection es de Surete Nucleaire – CEA, Fontenay-Aux-Roses, France; 1 Cigarettes box size LETS and Simple CIU, 1 large LETS will be used on Air France aircraft;

-Dr. P. Bilski, Health Physics Laboratory, Institute of Nuclear Physics, Krakow, Poland - 1 large LETS and simple CIU;

-Dr. Les Bennett, ROYAL MILITARY COLLEAGUE, Ontario, Canada - 1 large LETS and simple CIU;

-Dr. Jose Carlos Saez-Vergara, CIEMAT, and Dr. Dr. Ramón Domínguez-Mompell, IBERIA, Health Services, Aeropuerto de Barajas, Madrid – 2 Liulin-4S LETS with GPSs and rechargeable battery packages.

<u>References</u>

1. Dachev, Ts. P., Yu. N. Matviichuk, J. V. Semkova, R. T. Koleva, B. Boichev, P. Baynov, N. A. Kanchev, P. Lakov, Ya. J. Ivanov, P. T. Tomov, V. M. Petrov, V. I. Redko, V. I. Kojarinov, R. Tykva, Space radiation dosimetry with active detections for the scientific program of the second Bulgarian cosmonaut on board the Mir space station, Adv. Space Res., 9, 10, 247, 1989.
2. Dachev, Ts. P., Yu. N. Matviichuk, N. G. Bankov, Ya. J. Ivanov, B. T. Tomov, V. M. Petrov, V. I. Redko, M. V. Zil, V. G. Mitrakas, T. N. Smirnova, V. V. Temny, Yu. N. Ponomarev, R. Tykva, "Mir" Radiation Dosimetry Results during the Solar Flares events in September-October 1989, Adv. Space Res., 12, 2-2, (2)321-4, 1992.
3. Dachev Ts.P., J.V.Semkova, Yu.N.Matviichuk, R.T. Koleva, B.T. Tomov, P.T. Baynov, J.F. Bottollier- Depois, V.D. Nguen, L. Lebaron-Jacobs, M. Siegrist, E. Duvivier, B. Almarcha, V.M. Petrov, V.V. Shurshakov, New results for the space radiation environment of MIR space station obtained by Liulin dosimeterradiometer. Comparison with let spectrometer NAUSICAA, Acta Astronautica, vol.36 ,Nos 8-12, pp 505-515 ,1995.
4. <u>Dachev Ts.P., J.V. Semkova, Yu.N. Matviichuk, B.T. Tomov, R.T. Koleva, P.T. Baynov, V.M. Petrov, V.V. Shurshakov, Yu. Ivanov, Inner Magnetosphere Variations after Solar Proton Events. Observations on Mir Space Station In 1989-1994 Time Period, Adv. Space Res., 22, No 4, 521, 1998.</u>
5. Dachev, Ts., J. Semkova, V. Petrov, V. Redko, V. Bengin, T. Kostereva, J. Miller, L. Heilbronn, C. Zeitlin, Analysis of the pre -flight and post-flight calibration procedures performed on the LIULIN space radiation dosimeter, Acta Astronautica, 42, 375, 1998.
6. <u>Dachev, Ts.P. B.T. Tomov, Yu.N. Matviichuk, R.T. Koleva, J.V. Semkova, V.M. Petrov, V.V. Benghin, Yu.V. Ivanov, V.A. Shurshakov, J. Lemaire, Detailed Study of the SPE and aheir Effects on the Dose Rate and Flux Distribution Observed by LIULIN Insrtument on MIR Space Station, Radiation measurements, 30 (3), pp. 317-325, 1999.</u>
7. <u>Dachev, Ts.P. B.T. Tomov, Yu.N. Matviichuk, R.T. Koleva, J.V. Semkova, V.M. Petrov, V.V. Benghin, Yu.V. Ivanov, V.A. Shurshakov, J. Lemaire, Solar Cycle Variations ff MIR Radiation Environment as Observed by the LIULIN Dosimeter, Radiation Measurements, 30 (3), pp. 269-274, 1999.</u>

7a. Dachev, Ts.P., E.G. Stassinopoulos, B.T. Tomov, Pl.G. Dimitrov, Yu.N. Matviichuk, V.A. Shurshakov, V.M. Petrov, Analysis of The Cyclotron Facility Calibration and Aircraft Results Obtained By LIULIN-3M Instrument. (Will be published in ASR, 2003.)

7b. Stassinopoulos E.G. C.A. Stauffer, T.P. Dachev, C.J. Brucker, B.T. Tomov, P.G. Dimitrov, The LIULIN-3M Radiometer for Measuring Particle Doses in Space and on Aircraft, NASA/TM-2002-210003, February, 2002.

8. Dachev, Ts.P., B.T. Tomov, Pl. Dimitrov, G. Georgiev, Yu.N. Matviichuk, N.A. Kanchev, V.M. Petrov, V.A. Shurshanov, E.G. Stassinopoulos, J. Bart, Analysis of the cyclotron facility calibration results obtained by the Engineering model of Liulin-3 dosimeter-radiometer, Proceedings of the 3th National Konference on Solar-Terrestrial Influences, 73-75, Sofia, June 1996. (In Bulgarian)

9. Stassinopoulos, E.G., C.A. Stauffer, T.P. Dachev, C.G. Brucker, B.T. Tomov, P.G. Dimitrov, The Liulin-3M Radiometer for measuring particle doses in space and on aircraft, NASA/TM-2002-210003, NASA-GSFC, February 2002.

10. Lemaire, J., V. Pierrard, M. Echim, T. Dachev, M. Cyamukungu, C. Gregoire, Recent Progress in modeling the plasmasphere, energetic particles, as well the interaction between the solar wind and the magnetosphere, Space Scientific Research in Belgium, V II, Part 2 - 1994-2000, 27-46, 2002.

10a. Dachev Ts., B. Tomov, Yu. Matviichuk, Pl. Dimitrov, D. Mishev, D.-P. Häder, G. Horneck, G. Reitz, Description of the R3D Instrument for the ROSE Experiment on ISS, Proceedings of 7th STIL-BAS conference, 173-176, Sofia, November, 2000.

10b. R3D-B, Radiation Risk Radiometer-Dosimeter on Biopan (Foton) and expose on International Space Station, Streb, C., P. Richter, M. Lebert, T. Dachev, D-P. Haeder, Proceedings of the Second Exo-Astrobiology workshop, Graz, Austria, 71-74, ESA SP-518, November, 2002.

11. Dachev, Ts., B. Tomov, Pl. Dimitrov, Yu. Matviichuk, K. Fujitaka, Y. Uchihori, H. Kitamura, Calibration of LIULIN-4 type system at HIMAC with heavy ions, 1999 Annual Report of the Research Project with Heavy Ions at NIRS-HIMAC, NIRS, 299-300, April 2000.

12. Dachev Ts., B. Tomov, Pl. Dimitrov, Yu Matviichuk, Y. Uchihori, H. Kitamura, K. Fujitaka, Calibration of LIULIN-4 type system at HIMAC with heavy ions (11P-084), 2000 Annual Report of the Research Project with Heavy Ions at NIRS, NIRS-M-147, 281-282, April 2001.

13. Reitz, G., R. Beaujean, Ts. Dachev, S. Deme, M. Luszik-Bhadra, W. Heinrich, P. Olko and M. Scherkenbach, ISS Radiation Measurements Using the Dosimetric Mapping Experiment, paper F2.5-0013-02 presented at 34th COSPAR Assembly, Houston TX, 10-19 Oct. 2002.

14. Y. Uchihori, E. Benton, J. Moeller, Radiation Measurements Aboard NASA's Er-2 High Altitude Aircraft with the Liulin-4J Portable Spectrometer, paper F2.4-0012-02 pres. at 34th COSPAR Assembly, Houston TX, 10-19 Oct. 2002.

15. Spurný F., Ts. Dachev, Long-Term Monitoring of the Onboard Aircraft Exposure Level With Si-Diode Based Spectrometer, paper F2.4-0007 presented at 34th COSPAR Assembly, Houston TX 10-19 Oct. 2002.

16. Dachev, Ts., B. Tomov, Yu. Matviichuk, Pl. Dimitrov, J. Lemaire, Gh. Gregoire, M. Cyamukungu, H. Schmitz, K. Fujitaka, Y. Uchihori, H. Kitamura, G. Reitz, R. Beaujean, V. Petrov, V. Shurshakov, V. Benghin, F. Spurny, Calibration Results Obtained With Liulin-4 Type Dosimeters, Adv. Space Res., 2002. (in press)

17. Uchihori, Y., H. Kitamura, K. Fujitaka, Ts.P. Dachev, B.T. Tomov, P.G. Dimitrov, Y. Matviichuk, Analysis of the calibration results obtained with Liulin-4J spectrometer-dosimeter on protons and heavy ions, Radiation Measurements, 35, 127-134, 2002.

18. Kanai T., private communication, 1998.

19. Friedberg, W. Snyder, D.N. Faulkner, Radiation Exposure of Air Carrier Crew Members II, US FAA Report DOT/FAA/AM-92-2, 1992.

20. T.P. Dachev, F. Spurny, G. Reitz, R. Beaujean, S. Burmeister, V. Shurshakov, B.T. Tomov, P.G. Dimitrov, Y.N. Matviichuk, N.G. Bankov, Comparison of the Space Radiation Environments at Aircraft Altitudes and on International Space Station for April - August 2001, paper F2.4-0009-02 presented at 34th COSPAR Assembly, Houston TX, 10-19 Oct. 2002.

21. Dachev, Ts., J. Semkova, V. Petrov, V. Redko, V. Bengin, T. Kostereva, J. Miller, L. Heilbronn, C. Zeitlin, Analysis of the pre-flight and post-flight calibration procedures performed on the LIULIN space radiation dosimeter, Acta Astronautica, 42, 375, 1998.