SPACE RADIATION DOSIMETRY SYSTEM FOR THE RUSSIAN SEGMENT OF THE INTERNATIONAL SPACE STATION

Tsvetan Panteleev Dachev[1], Borislav Todorov Tomov[1], Yiri Nikolaevich Matviichuk[1], Plamen Georgiev Dimitrov[1], Vladislav Mihailovich Petrov[2], Vyacheslav A. Shurshakov[2]

[1]Solar-Terrestrial Influences Laboratory - BAS, Sofia, Bulgaria, tdachev@bas.bg
[2]Institute of Biomedical Problems, Moscow, Russia, petrov@mmcc.ibmp.rssi.ru

Summary: The Space Radiation Dosimeter System (Liulin-MKS) is a part of the Russian Space Radiation Control System (SRCS). The SRCS on the Russian segment of International Space Station (ISS) must ensure the radiation safety of cosmonauts. SRCS will evaluate radiation loading on cosmonauts' organs; monitor and predict radiation environment during the mission; supply the Radiation Safety Service with data regarding radiation conditions along the trajectory and on board of spacecraft; inform cosmonauts about radiation risk levels including warning and recommending protection actions, and etc. The Liulin-MKS main purpose is to monitor simultaneously the personal doses and fluxes at four independent places of the station. During Solar Proton Events the system is used for personal monitoring of the doses and fluxes obtained in 5 days by 3 selected cosmonauts. On the transport vehicle "Progress" Liulin-MKS will measure the vertical profiles of the near Earth radiation environment. Liulin-MKS data are transmitted by RS-485 to the SRCS hard disc drive under CAN-2B protocol. Further the data are passed to the Earth. Liulin-MKS consists of 4 Mobile Dosimeter Units (MDU) and one Control and Interface Unit (CIU). The development of the subsystem will allow extending of the number of MDUs and ICUs up to 64. The MDU is a miniature spectrometer-dosimeter containing one semiconductor detector, one charge-sensitive preamplifier, 3 microcontrollers; a flash memory and Li-Ion cells. Pulse analysis technique is used for the measurement of the deposited energy in the 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 through the Control and interface unit toward the SRCS. 28 V DC current is used for recharging of the Li-Ion sells in the MDUs. CIU is a miniature interface between the ISS power system and the MDUs. SRCS provides to CIU a standard interface of RS-485 type and a power supply of +28 V DC. Liulin-MKS is developed in cooperation with Russian scientists from Institute of Biomedical Problems in Moscow. We describe the shape of the specters obtained at different sources and condition and the results obtained during the calibrations of the spectrometers at the Standard ^{137}Cs source located in the Institute for Qualification of medical doctors in Sofia.

LIULIN-MKS SYSTEM DESCRIPTION

Liulin-MKS system is developed under the experience obtained with the Liulin dosimeter-radiometer successfully flown on the MIR space Station in 1988-1994 time interval [1-3].

The system consists of 4 Mobile Dosimetry Units (MDU) and one Control and Interface Unit (CIU). The MDU is a miniature spectrometer-dosimeter and is designed for continuous monitoring of the ISS radiation environment. The MDU contains: one semiconductor detector; one low noise, hybrid, charge-sensitive preamplifier A225 type of AMPTEK inc.; a fast 12 channel ADC; 3 microcontrollers

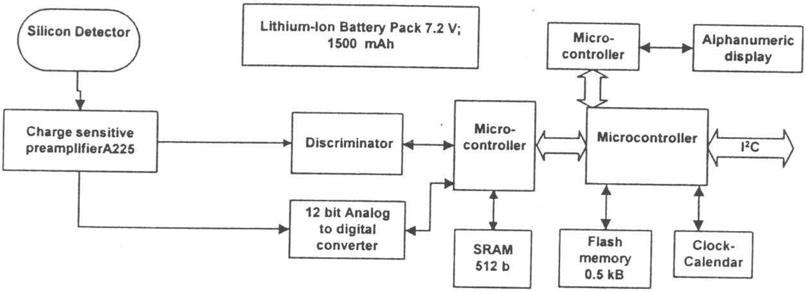

Figure 1. Block-scheme of the MDU

flash memory of 0.5 Mbytes and 8 character 5x7 LED matrix alphanumeric display. Pulse high analysis technique is used for measurement of the energy losses in the detector. The unit is managed by the microcontrollers through specially developed software. In the MDU a Lithium-Ion battery pack of SONY NP-F550 7.2 V, 1500 mAh type is used. The battery pack consists of 2 cylindrical cells SONY 18650 in 1S-1P configuration. A block schema of portable spectrometer-dosimeter in the MDU is presented in Figure 1.

After switching on, the MDU starts to separate in 256 channels the spectrum used 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 with 10-sec step. After finishing the first measurement cycle the spectrum, the accumulated dose and the 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 MDU with the CIU, the MDU transmits to CIU and further to PC all accumulated data.

The main measurement unit in the MDU is the amplitude of the pulses after the preamplifier, which is proportional by a factor of 240 mV/MeV to the energy loss in the detector and respectively to the absorbed dose in it. 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. The following method for calculations of the dose is used: The dose D [Gy] by definition is one Joule deposited in 1kg of matter or:

D = K.Sum(Ai*i)/MD,

where MD is the mass of the detector in [kg]. Energy loss in channel i is proportional to the number of events A_i in it multiplied by i. Energy loss in the whole detector is a sum of the energy losses in each channel. K is a coefficient. The MDU operate in 3 modes - Working mode, Mode of Data transfer from the flash memory to Control and interface unit and mode of battery recharging:

- In the Working mode the instrument is operating under the software in the microcontrollers. The operational time of the instrument depends on the lifetime of the accumulators and on the rate of the memory fills up. In a case of continuous operation the lifetime is about 120 hours with the standard 1350 mAh Li-Ion accumulators. 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 MDU's status indicator start to flash each second, signalizing the necessity for charging of the battery.

- In the mode of data transfer the instrument is switched on by special command when it is connected to one of the 4 sockets of the Control and interface unit after the end of the experiments. The mode allows the transfer of the accumulated in the flash memory data through the CIU to the PC. In this mode the connection of the data with real time and the calculation of the physical values is performed through a special program in the PC.

- The mode of battery recharging is performed when the batteries in MDUs are discharged. The batteries are charged inside of the MDUs with the 4 chargers in the CIU. Charging process is controlled by 4 LT1512 SEPIC Constant Current/Constant voltage battery chargers and is indicated by the red light on the CIU. When the red light on CIU is off the battery in the correspond MDU is fully charged i.e. the voltage on the battery is above 8.28 V. The charging process continues about 12 hours.

The-Control and Interface Unit (CIU) is a miniature interface between the external power supply, PC and MDUs. Power supply passes to the CIU DC current with the voltage in the interval +8.4 to 36 V DC (see Figure 2). 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 (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. 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 system information block the real calendar and clock time. These values are permanently with 10-sec step compared and updated if necessary with the new real data. Clock-calendar data are transmitted from CIU to each MDUs and used further to evaluate the measurements and to perform them in equal time interval at all 4 MDUs. Simply by default all MDUs produces 2 spectra per minute while the first spectrum is starting at 00 seconds and the second one at 30 seconds of each minute.

Time accuracy of the intervals in the different MDUs is about 10^{-5} s. Data accumulated in the flash memories of MDUs are transmitted through CIU to the PC

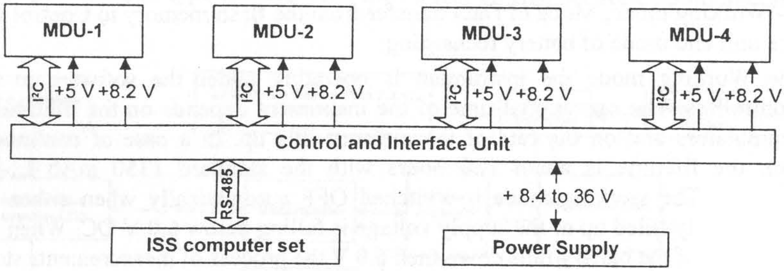

Figure 2. Place and functions of the Control and Interface Unit

by the serial interface connection using a CAN-2B protocol. The Liulin software product (Liulin-MKS.exe) is developed in "WIN95/NT" environment. At the PC it creates automatically the subdirectory "Liulin-MKS Data" in the directory in which "Liulin-MKS.exe" is located. In the subdirectory "Liulin-MKS Data" two types of files are automatically created. The binary file for each MDU is named automatically and contains in the name YYMMDDHHmm.LIx, where "YYMMDDHHmm" is the date and time of the first measurements with the MDU and "x" is the number of MDU. 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. Two 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 "DIx" and "SIx" contains the "D"ose and "S"pectrum data from each MDU.

LIULIN-4 CALIBRATIONS

Figure 3. presents 7 different experimental specters, which are obtained with one MDU at different sources and conditions. The lowest in intensity specter is obtained at natural background gamma radiation. Here we emphasize the fact that all MDUs do have enough sensitivity to register through conversion in electrons the natural background gamma radiation and when the value of the measured dose is in the range 0.07-0.14 μGy/hour this is used like a referent point for the appropriate working of the whole instrument. Another very low depositing energy specter is the X rays one.

The specter obtained from ^{137}Cs source as it is expected is very short because its gamma emission line is with energy of 661.7 keV. The neatest relatively short spectra is the ^{90}Sr one because the maximum energy of electrons emitted by it is 2.2 MeV. The last point in it is at 1.18 MeV, while the last point in the specter obtained during an airplane flight at about12 km altitude is at 6.14 MeV. In other cases at this altitude we observe energy depositions even above the range of the spectrometer, which is 20.7 MeV. The maximums of all described till now specters, except of ^{90}Sr, are situated at 122 keV, which is the expected energy loss by relativistic charged particles in 300 microns of silicon. The specter maximum by protons with 60 MeV energy is at 691 keV, while the GEANT code predictions is 710 keV. The most right shifted specter maximum is obtained by alpha particles and its maximum energy is 4.35 MeV. The energy reduction from the expected 5.485 MeV (^{241}Am alphas) can be explained by degradation in air.

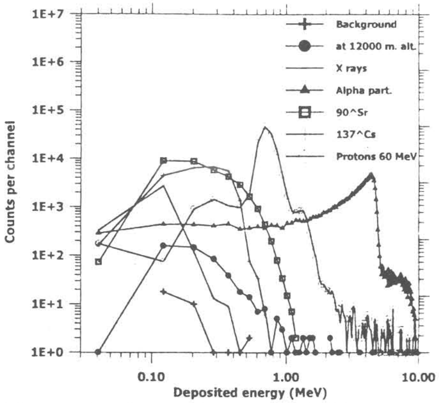

Figure 3 Comparison of MDU specters obtained by different sources and under different sources and conditions

Absolute dosimetric calibrations with standard ^{137}Cs source calibration was performed at the National Standard ^{137}Cs source located in the Institute for Qualification of medical doctors in Sofia. Two different MDUs were used to detect the gamma radiation from the source at 2 m distance. Behind the MDUs there was about 9 meters free space to avoid contamination of the measurements by reflection. One example of the observed mean specters is presented at Figure 5. Two different curves from the different MDUs are seen there, which overlap strongly because the very similar conditions and instrument setup. The absolute predicted at the point of the detectors of the MDUs dose is 3124 μGy/hour in air while the obtained in MDU 3 and MDU 4 doses are 3449.4 and 3459.6 μGy/hour in Silicon respectively,

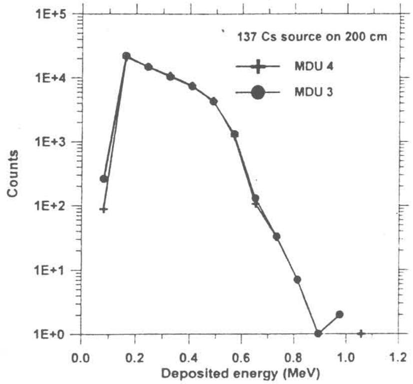

Figure 4 Specters obtained by standard ^{137}Cs source

which gives about 10% overestimation by Liulin.

CONCLUSDIONS

The results of our studies have shown, we believe, that the LIULIN-MKS dosimeter represent a very useful, versatile and flexible facility to monitor the absorbed dose and the charged particle fluence rates at the Russian segment of the ISS.

During the absolute dosimetric calibrations at the ^{137}Cs facility was found that Liulin dosimeters overestimated the predicted values by 10%. This result can be easy understand having in mind the fact that movement of the specter by 1 step in left or right direction bring ±40% differences in the dose.

As far as the absorbed dose rate is concerned it was shown that the dosimeter could reasonably correctly estimate the low LET radiation doses within the range of dose rates from the natural background (~ 100 nGy/h) up to, at least, few mSv/h. The minimum observed doses in a high-shielded environment by MDU is 44 nGy/hour. Some additional studies seem to be useful to verify the instrument's calibration using more large scale of particle types and theirs energies.

As far as the charged particle fluence rate is concerned, the instrument permits to register particles with fluence rates between 0.01 and 1000 cm^{-2} s. Spectrometry quality of the instrument permit to determine also the quality of radiation, i.e. the particle type and its energy in a case of simple radiation field. In more complicated radiation field the recognition of the primary radiation sources.

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REFERENCES

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, B.Ț. Tomov, V. M. Petrov, V. I. Redko, V. I. Kojarinov, R. Tykva, Space radiation dosimetry with active detection's 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., 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.

3. 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.