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MAIN SPECIFICATIONS OF A NEW LIULIN TYPE INTELLIGENT CREW PERSONAL DOSIMETER

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Abstract: *The 15-year development, calibrations and use of the Liulin type personal dosimeters confirm their reliability to measure the absorbed dose rates and fluxes in aircraft and spacecraft. Since 2002, many attempts were made to evaluate the equivalent doses from the spectra obtained by them. Now we are confident that apparent dose equivalent interpretation procedure in aircraft is well developed and can be used in a wide range of cases. On the other hand, the necessity for active crew dosimeter is a problem still not solved on the International Space Station (ISS). The 4-year efforts of the ESA study group headed by Dr. Guenther Reitz for development of new "European Crew Personal Active Dosimeter" (EuCPAD) for astronauts came to the result that this dosimeter has to be a mixture of modules for measurement of charged particles and neutrons with mechanical dimensions of maximum 105x67x20 mm, volume below 150 ml and mass below 250 g. This dosimeter is under development*

The purpose of this paper is: 1) To present the developed Liulin personal devices and to compare their dimensions with the proposed EuCPAD 2) To review the existing Liulin dose interpretation and radiation sources separation procedures 3) To propose a new "Intelligent Crew Personal Active Dosimeter" (ICPAD) based on the existing Liulin type devices, which can be used by astronauts in internal and external vehicle activities. The possible improvements are seen in both the hardware and the software aspect. The new software will be capable, based on the analysis of the shape of the deposited energy spectrum and the value of the dose-to-flux ratio, to distinguish the different kinds of radiation sources in space as GCR, inner radiation belt protons and outer radiation belt electrons and to calculate, store and present on display the absorbed and equivalent doses.

ГЛАВНИ СПЕЦИФИКАЦИИ НА НОВ, ИНТЕЛИГЕНТЕН, ПЕРСОНАЛЕН ДОЗИМЕТЪР ЗА КОСМОНАВТИТЕ

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Ключови думи: *Космическа радиация, Дозиметрия, Спектрометрия.*

Резюме: *15 годишното усъвършенстване, калибриране и използване на персонални дозиметри от типа „Люлин" е доказало тяхната способност да измерват мощността на абсорбираната доза в самолети и спътници. След 2002 г. са направени многобройни опити за оценка на еквивалентната доза, като се използват получените от тях спектри. Сега ние сме сигурни, че процедурата за интерпретация на видимата еквивалентна доза на самолети е добре разработена и може да бъде използвана в широк кръг от задачи. От друга страна не е решен проблемът за създаване на активен, персонален дозиметър на Интернационалната космическа станция. Изследователската група на ЕКА, оглавявана от д-р Гюнтер Райтц за създаване на нов „Европейски, активен, персонален дозиметър" (EuCPAD) за астронавтите постигна следния резултат за неговата същност и размери: EuCPAD*

трябва да съдържа модули за измерване на дозата от заредени частици и от неутрони и да има размери не по-големи 105x67x20 mm, обем под 150 ml и маса под 250 g. Този проект за дозиметър се намира във фаза на разработка.

Целта на тази статия е: 1) Да се представят разработените досега персонални дозиметри от типа „Люлин“ и да се сравнят техните размери с предложения EuCPAD; 2) Да се анализират съществуващите процедури за интерпретация на дозата и за разделяне на преобладаващия тип радиация. 3) На базата на съществуващите прибори от типа „Люлин“ да се предложи нов „Интелигентен, персонален, активен дозиметър“ (ICPAD), който да бъде използван от астронавтите при работа както вътре в станцията, така и извън нея. Подобренията са възможни както в областта на хардуера, така и на софтуера. Чрез анализ на формата на спектъра и на стойността на отношението доза поток ще може да се разделят различните основни типове радиационни източници като GCR, протони от вътрешния и електрони от външния радиационен пояс. Тези данни да се използват да се изчисли, съхрани и покаже на дисплей абсорбираната и еквивалентната доза.

Introduction

The main purpose of Liulin type Spectrometry-Dosimetry Instruments (LSDIs) (please see Table 1) is cosmic radiation monitoring 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.

Table 1. External view and some functional parameters of the developed till now personal units.

Picture/Parameters	**Name (year of the development) Use (years)**	**Dimensions (mm) (Reference)**	**Volume (ml)**	**Mass (g)**	**Battery type**	**Active live time (days)**
	**Liulin-3** 2 detectors telescope (1995) Aircraft & accelerators (1995-1997)	150x80x50 (Дачев и др., 1995)	600	450	4 AA size primary	1
	**Liulin-E094**, 4 Mobile Dosimetry Units (MDU) (1998) ISS (2001) & aircraft (2005-till now)	96x64x24 (Dachev et al., 2002)	147	230	Li-ion 7.2 V 1350 mAh accum.	4
	**Liulin-ISS** 4 MDU units (2002) (2005-till now)	100x65x26 (Dachev et al., 2000)	188	230	Li-ion 7.2 V 1350 mAh accum.	6
	**Liulin-6S** (2005) Aircraft & accelerators (2005-till now)	100x40x20 (Dachev et al., 2005)	80	100	Li-ion 3.6 V 1.8 Ah accum.	7
	**Liulin-6G** (2008) Aircraft (2008-till now)	120x40x20 (Dachev et al., 2005)	96	125	Li-ion 3.6 V 1.8 Ah accum.	5
	**Portable EuCPAD instrument** ISS ???	Maximum 105x67x20 (Reitz, 2008)	Below 150	Below	???	???

These amplitudes are organised 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 (Dachev, 2009). The LSDI functionally is low mass, low power consumption or battery operated dosimeter. 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, multimedia card (MMC) or SD card.

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 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.

Presentation of the developed Liulin personal devices and comparison of their dimensions with the proposed EuCPAD

Table 1 summarizes the efforts in STIL-BAS for developments of Liulin personal devices since 1995. Most of them are with simple 1 detector construction. Also most of them used Li-ion accumulators as power supply. This option don't have alternative if long active live time of the detector is required.

From the table it is seen that because use of new developed chips and design in the time between 2002 and 2008 the volume of the LSDIs reduces from 147 to 80 ml for instruments without display and from 188 to 96 ml for the instruments with display.

From other point of view the developed by us LSDIs are much smaller than the expected new Portable EuCPAD, which is still not designed newer the less that much higher scientific (Bhadra et al., et al., 2008; Rollet et al., 2008) and financial resource was used by the ESA partners, engaged with the development of the dosimeter (Retz et al., 2008). The best claimant for the external design of the future New Liulin type Intelligent Crew Personal Active Dosimeter (ICPAD) is the Liulin-6G instrument if a display will be required there. If in future the user will not require a display the best design is those of Liulin-6S. In both cases future use of Lithium-Polymer cells can reduce the mass of the battery at least twice in comparison with the standard Lithium-ion cells. http://www.ibt-power.com This means about 15 g less weight with the same case.

Review the existing Liulin ration dose interpretation and radiation sources separation procedures

The main measurement unit in the spectrometers is the amplitude of the pulse after the preamplifier generated by particles or quantum hitting the detector. The amplitude of the pulse is proportional by a factor of 240 $mV.MeV^{-1}$ 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 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.

(1) $$D = K\sum_{i=1}^{255} ik_i A_i MD^{-1}$$

where *MD* 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 255 deposited dose values, depending on the deposited energy for one exposure time, form the deposited energy spectrum.

On the basis of calibrations of the Liulin type spectrometers in CERN and comparisons with TEPC (Tissue Equivalent Proportional Counter) measurements, a method was developed (Spurny et al., 2007) to evaluate Ambient dose equivalent, H*(10).

During the calibrations in CERN it was found the value of the ambient dose equivalent - H*(10) depends by the predominant type of radiation seen in the deposited energy spectrum. For the Galactic cosmic radiation (GCR) where predominant are high energy protons, alphas and heavy ions with high radiation biological effectiveness (RBE) the H*(10) values are calculated by the relation (2), which take into account the high RBE by the coefficient of 5 for the channels above 15. The final relation for calculation of the H_{GCR} *is as following:*

(2) $$H_{GCR}*(10) = K\{\sum_{i=1}^{14} ik_i A_i + 5\sum_{i=15}^{256} ik_i A_i\}MD^{-1}$$

For the Inner radiation belt (IRB) source, where predominant radiation source are protons with energies between 30 and 400 MeV the H*(10) values are calculated by the relation

(3) $$H_{GCR}*(10) = 1.3K\{\sum_{i=1}^{14} ik_i A_i + \sum_{i=15}^{256} ik_i A_i\}MD^{-1}$$

For the Outer radiation belt (ORB) radiation the H*(10) values are equal to the absorbed doses, because energetic electrons (1-10 MeV), which populated it don't have any radiation biological effectiveness.

Long-term measurements in space by the active dosimeters as Liulin-E094, R3D-B2/3, R3DE/R and RADOM give us abundant material for the methods to distinguish different kind of predominant radiation by the form of the curve of the deposited energy spectrum and by the calculation of the dose to flux ratio and Heffner's formulae (Dachev, 2009).

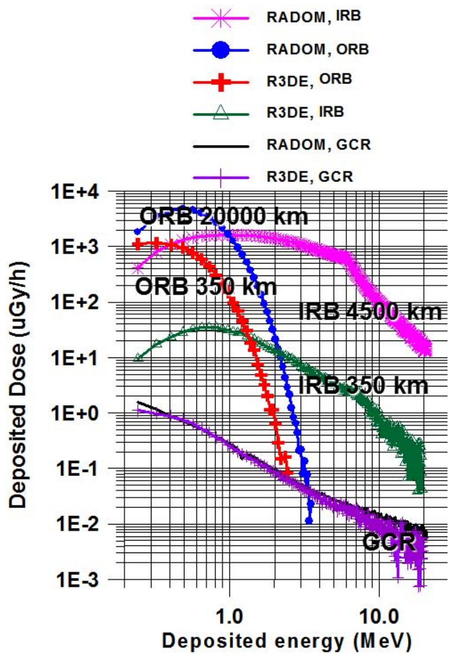

Fig. 1. General presentations of different spectra shapes obtained by R3DE and RADOM instruments. The lowest 2 curves are associated with GCR type of radiation environment. The IRB curves cover the whole spectrum, while the ORB are in narrow range of first channels.

Figure 1 presents six averaged deposited energy spectra obtained by R3DE (Dachev, 2009) and RADOM instruments (Dachev et al., 2009, 2011). RADOM data are from October 2008 when the Chandrayaan-1 satellite was still in near Earth radiation environment. Three pairs of curves are plotted. The lowest 2 curves are associated with GCR type of radiation environment. The IRB curves cover the whole spectrum, while the ORB are in narrow range of first channels. On Figure 1 it is well seen that different type of radiation give forms of the deposited energy spectra, which are easy to distinguish by their form and position in the field Deposited energy/Deposited per channel Dose Rate. We plan to develop and prove different software, which will be able after obtaining of the spectra, using the master microprocessor of ICPAD to answer correctly what is the predominant radiation in the spectra.

Another procedure for distinguishing the predominant different kind of radiation sources was described in (Bankov et al., 2010). It is based on the polynomial presentation of the obtained doses in dependence by L value, which requires connection of the ICPAD trough Internet WLAN module with the ISS service system.

Proposal for a new "Intelligent Crew Personal Active Dosimeter" (ICPAD)

Starting the development of the new ICPAD we study the advantages and disadvantages of the main schema of the new instrument – dosimetric telescope (Semkova et al., 2007) or single detector as the existing till now Liulin devices. The main advantage of the dosimetric telescope is the opportunity to be obtained directly the Linear Energy Transfer (LET) spectrum, which is used further for calculation of the equivalent dose. Unfortunately this is not possible to be performed after obtaining of each spectrum because the small statistics (Semkova, 2010). The disadvantages of the dosimetric telescope for the case of personal dosimeter are larger volume, mass and power consumption in comparison with single detector. That is why we decide to propose single detector instrument with following size and ranges:

Size: <120x40x20 mm; Mass: <110 grams; Volume:<96 ml
Detector: 2 cm^2, 0.3 mm;
LET Si range: 0.1164- 29.8 keV/μ; LET H2O: 0.1443- 36.9 keV/μ
Dose range: 0.093 nGy – 1.56 mGy; Dose Rate range: $2.8.10^{-9}$-0.19 Gy/h
Flux range: 0.01 – 1250 cm^2s-1; Temperature: -20°C - +40°C
Li-Ion battery: 3.6 or 7.2 V; Flash memory: 2 MB
Active time: >5 days

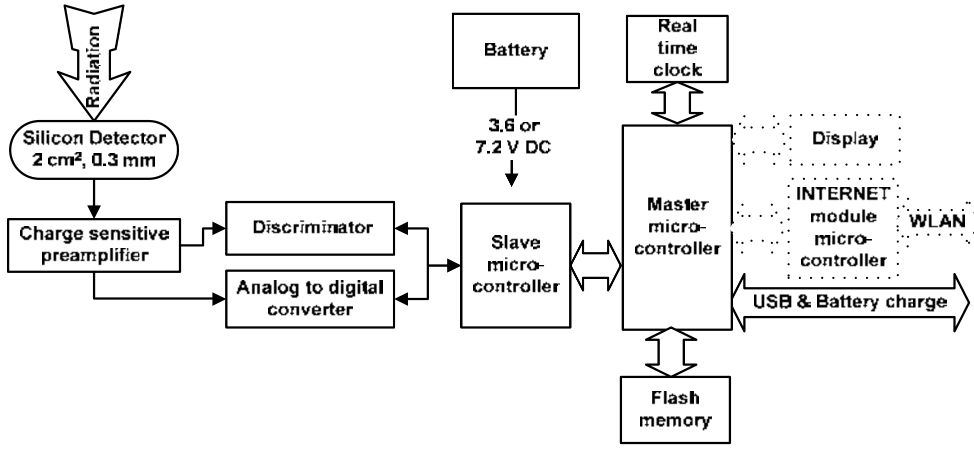

Fig. 2. Preliminary block-diagram of the new Intelligent Crew Personal Active Dosimeter. Blocks with dashed lines are optional.

Figure 2 presents the preliminary block-diagram of the proposed ICPAD. It is necessary to mention that the main blocks is same as the used till this moment blocks in the instruments build for different space experiments between 2001 and 2010 (Dachev, 2009). New are here only the 2 optional blocks seen in the right part of the figure with dashed lines and mentioned as “Display” and WLAN “Internet module microcontroller”.

The display is optional because our experience with the development of the MDUs for Liulin-E094 and Liulin-ISS (pls. see Table 1) shows that the different agencies American and Russian have controversial understanding of the necessity of display. The WLAN connection with the ISS service system can be used in both directions. To transmit to ICPAD new measurement initialization parameters and L values. In the case of use of the ICPAD as personal dosimeter to transmit toward the Radiation protection service system the current obtained by the astronaut doses, which can be added to the whole personal file, to be evaluated the personal history of the dose accumulation and to be issued to the astronaut specific alerts if necessary.

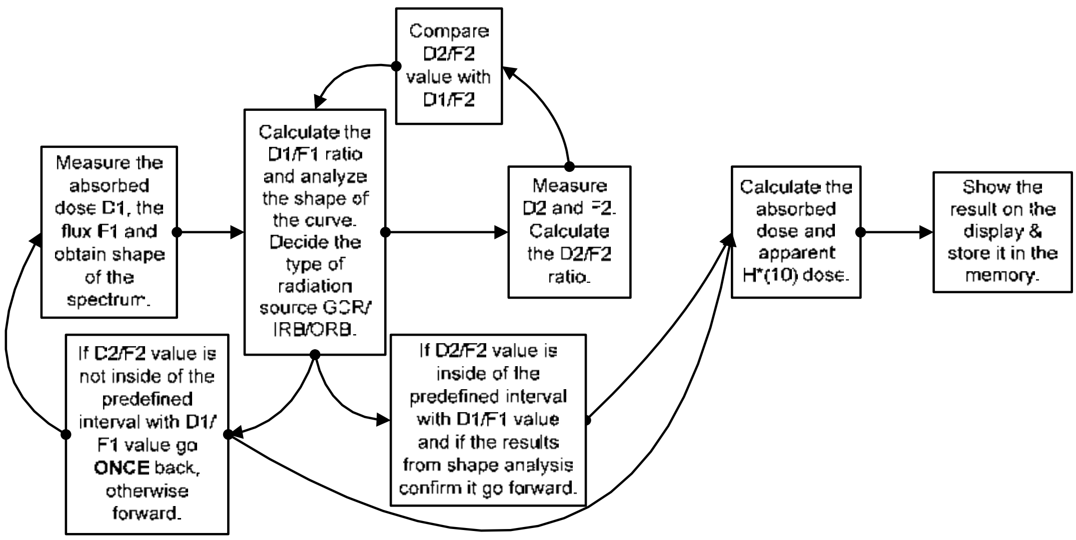

Fig. 3. Preliminary algorithm of the software, which well manage the new Intelligent Crew Personal Active Dosimeter.

Figure 3 presents the preliminary algorithm of the software, which will manage the ICPAD. The first 2 step is the measurements of the dose rate D1 and flux F1 and analysis of the shape of the curve. The results are compared and stored in the memory. Next step is a confirmation measurement of 2 new D2, F2 values. These values are compared with the obtained in the first step. If all parameters (D1/F1, D2/F2 and shape) confirm the solution the algorithm goes forward, calculates the absorbed and apparent H*(10) dose rates and shows them on the display (if available), and stores them in the memory. If the solution is not confirmed then the algorithm goes once back otherwise forward.

The foreseen external view of the ICPAD will be similar and smaller than the Liulin-6S in a case without display and then Liulin-6G with display (please see Table 1).

Summary

The ability of the Liulin type instruments to be used as personal dosimeters are mentioned in the conclusions of the paper of Uchihori at al., 2008. They write: “We demonstrated that the MDU can measure lower LET ions and particles from “Fragment experiments” despite the fact that the instrument is both simple and small. In the space radiation environment, the majority of radiation fluence consists of protons and helium ions. The Liulin-4J MDU has the capability to measure the radiation dose from these light ions and can be used as a personal dosimeter by astronauts and cosmonauts”.

The paper describes the possible hardware and software solutions for a new ICPAD, which will be able on the base of the analysis of the shape of the deposited energy spectrum and the value of the dose to flux ratio to distinguish the different kind of radiation sources in space as GCR, Inner radiation belt protons and outer radiation belt electrons and to calculate, store and present on display the absorbed and equivalent doses.

Acknowledgments

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