Investigation of the dosimetric parameters of the PorTL thermoluminescent dosimetry system

Péter Szántó[1], István Apáthy[1], László Bodnár[2], Sándor Deme[1], Annamária Kéri[3], Saveta Miljanić[4], Tamás Pázmándi[1], Branko Vekić[4]

[1]Hungarian Academy of Sciences Centre for Energy Research, Konkoly Thege Miklós u. 29-33, Budapest, Hungary, H-1121

[2]BL Electrocics Ltd, , Solymar, Sport 5., Hungary, H-2083

[3]Budapest University of Technology and Economics, Műegyetem rakpart 3-9., Budapest, Hungary, H-1111

[4] Ruđer Bošković Institute, Bijenička cesta 54, Zagreb, Croatia, HR-10000

Abstract

The development of the PorTL system was based on the Pille thermoluminescent space dosimetry system, which has been on board all space stations orbiting the Earth since 1980. The latest version of the Pille system, provided more than 30 000 valuable read-outs on board the International Space Station including personal dose data of extravehicular activities and high resolution dose monitoring.

The main goal of the development of the PorTL system was to combine the reliability and robustness of the Pille system with the expectations for a common-use dosimeter system. Therefore, the main structure of the reader device was preserved, and several user friendly features were added.

The PorTL dosimeters consist of a suitably positioned TL material fixed to a heating plate, a thermometer and a memory chip storing the unique calibration parameters of the corresponding dosimeter. The PorTL system is currently available with Al_2O_3:C as well as ^{6}LiF, ^{7}LiF, and ^{nat}LiF TL materials. During the read-outs, the reader device heats the dosimeters and registers the TL glow curve. The reader also performs preliminary evaluation of the data. The glow curve and the derived data are saved in the memory of the device and can be downloaded via serial connection to a computer. Software for managing data downloads and dosimeter calibration, performing glow curve visualization and detailed data evaluation is also available.

The main dosimetric parameters of the PorTL system were measured during the past years according to the IEC 61066 International Standard for Thermoluminescence dosimetry systems for personal and environmental monitoring. The linearity, the reusability as well as the radiation energy and angle of incidence dependence were measured.

The results of the investigations of the main dosimetric parameters of the PorTL system are presented in this paper.

Key words: Dosimetry, TL, Thermoluminescence

Introduction

Dose measurements are of high importance in workplaces utilizing ionizing radiation such as medical diagnostic or therapeutic facilities, nuclear power plants or research institutes. The accurate measurement of dose makes it possible to fulfill the principles of radiation protection set up by ICRP, to keep the dose exposures justified, limited and optimized.

The PorTL System, a portable, lightweight thermoluminescent (TL) dosimeter system developed by the Hungarian Academy of Sciences Centre for Energy Research consists of a relatively small size reader device and a set of special dosimeters. The development was based on the Pille thermoluminescent space dosimetry system, which has been on board all space stations orbiting the Earth since 1980. The latest version of the Pille system, which has been the service dosimeter system of the Russian expeditions of the International Space Station since 2003, provided more than 30 000 valuable read-outs on board the station including personal dose data of extravehicular activities and high resolution dose monitoring.

The main dosimetric parameters of the PorTL system were measured during the past years according to the IEC 61066 International Standard for Thermoluminescence dosimetry systems for personal and environmental monitoring. The linearity, the reusability as well as the radiation energy and angle of incidence dependence were measured.

X-ray measurements were performed at the Ruđer Bošković Institute, Zagreb and in the Hungarian Academy of Sciences Centre for Energy Research under the frames of TéT Croatian-Hungarian International cooperation programme.

Methodology

Thermoluminescent dosimeters are commonly used for personal and environmental measurements. A TL dosimeter system consists of a certain number of TL dosimeters and a reader device. Each dosimeter contains a piece of TL material, usually a doped inorganic crystal. If a TL material is exposed to ionizing radiation, its valence electrons get to an excited state, in which way it “absorbs” a part of the radiation energy. If the irradiated TL material is heated, these electrons fall back to their ground state while emitting photons. The number of photons emitted is proportional to the number of excited electrons being proportional to the amount of radiation the crystal was exposed to. Thus, by measuring the light emitted, the dose absorbed can be determined.

The TL dosimeters are passive integrating sensors. They are small, durable and do not need any power during the exposition (measurement). Their sensitivity and stability is good and have a wide measuring range. Beyond these advantages, TL dosimeters need a reader device for the evaluation of the measurements after the exposition. The reader heats the TL material and measures the light emitted during heating; the dose absorbed is calculated from the integrated light intensity.

Instrumentation

The PorTL Dosimeter System was developed based on the Pille Space Dosimetry System. The light weight (1.4 kg) and the small size of the Pille reader allow the Pille system to be the only TL dosimeter system capable of carrying out readouts onboard spacecrafts. The main goal of the development was to combine the flexibility, reliability and robustness of the space qualified Pille system with the expectations for a common-use dosimeter system. Therefore, the main structure of the reader device was preserved, and several user friendly features were added.

The PorTL system consists of a reader device and several dosimeters. [3]

The TL block inside the PorTL dosimeters (Fig. 1) consists of a ceramic plate with a miniature heater fixed on one side and a TL tablet (Al_2O_3:C or LiF) on the other side. Between the plate and the tablet, a thermocouple is located for measuring the actual temperature of the tablet during the heating period.

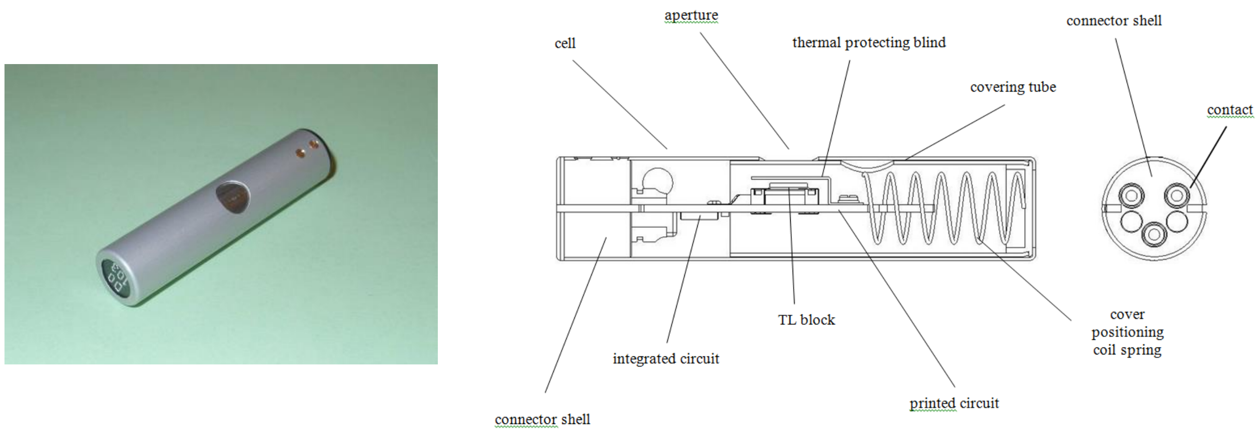

Fig. 1: PorTL dosimeter

The TL block is encapsulated in a small, closed cylindrical metallic cell (cartridge) for protecting it against mechanical effects and light exposure, containing additional components and providing electrical interface to the reader. In its basic position the aperture of the cell is closed by a covering tube inside, positioned by a coil spring. At inserting the dosimeter into the reader, the covering tube is shifted back opening the aperture and clearing the way for the light emitted by the TL material towards the photomultiplier tube.

There is an integrated circuit (IC) located in each dosimeter. The individual identifier and the calibration parameters of the dosimeter are stored in the flash memory of this IC. Other circuits of the IC convert the voltage of the thermocouple (proportional to the temperature of the TL material) to a digital signal for the reader. The plated contacts used for leading the heating current into the dosimeter and for communicating with the IC inside it are built in a plastic connector shell fixed in one end of the dosimeter.

More than twenty different types (using different TL materials, heating parameters etc.) and 10 000 different species of each type of dosimeters can be identified automatically, read out and evaluated automatically using their individual calibration parameters. The identification codes and the individual parameters of the dosimeters as a result of their calibration can be programmed via the reader by a PC, using a special application software.

The PorTL reader (Fig. 2) is a small, portable, microprocessor controlled equipment. The built-in rechargeable battery makes it suitable for outdoor measurements as well. The menu commands, parameters, and the results of measurements are visualized on a graphic liquid crystal display (LCD).

Fig. 2: PorTL reader device

The most important component of the light detection system is the photoelectron multiplier tube (PMT) capable of converting extremely weak light to a measurable current on one hand and having a very wide measuring range on the other.

The measured dose can be obtained by the mathematical evaluation of the glow curve i.e. the anode current curve of the PMT is proportional to it. The anode current of the PMT is converted to a voltage and digitized for the CPU by an A/D converter of 12-bit resolution. The range of the light detecting system exceeds 8 orders of magnitude. The light sensitivity of the reader is checked prior to each read-out automatically and can be checked by command as well by a built-in stabilized LED (light-emitting diode) control light source.

The reader is controlled by a user-friendly menu system. There are 6 pushbuttons on the front panel for navigating between the menu items and setting the alphanumeric values, and a graphic liquid crystal display (LCD) with a resolution of 192×64 pixels for the visualization of the result of measurements, the parameters and the menu system.

Using the digital thermometer built in the structure of the reader the influence of the environmental temperature is taken into account by the operational software during the evaluation, allowing a wide operational ambient temperature range (-20…+40 °C). The operating software, the reader-specific and partly the cell-specific parameters as well as the results of the measurements (not more than 1920 data blocks) are stored in a flash memory. The reader can be connected to a personal computer via its RS-232 standard serial port.

Experiment and results

The main dosimetric parameters of the PorTL system with ^{6}LiF and ^{7}LiF dosimeters were measured during the past years according to the IEC 61066 International Standard for Thermoluminescence dosimetry systems for personal and environmental monitoring. The linearity, the reusability as well as the radiation energy and angle of incidence dependence were measured.

Six dosimeters were used during the experiment. The identification numbers and the TL materials of the dosimeters are shown in Table 1. The calibration of the dosimeters was performed with ^{137}Cs source, and with exposure of 2 mGy. The dosimeters were irradiated in their plastic case. According to the IEC 61066 standard, the dosimeter system was calibrated to display the measurement result in Sv [1]. The dose conversion coefficient of 1.2 was used during the calibration (Table 3). [2]

Table 1: The dosimeters used in the experiment

dosimeter ID	TL material	dosimeter ID	TL material
X0039	^{6}LiF	X0043	^{7}LiF
X0040	^{6}LiF	X0044	^{7}LiF
X0041	^{6}LiF	X0045	^{7}LiF

The detection limit of the dosimeters was determined as the standard deviation of the TL signal of the unirradiated dosimeters. Each dosimeter was read out 16 times without irradiation cyclically, so the time between the read-outs of an individual dosimeter was 5-10 minutes. Assuming that the (natural) background dose rate in the laboratory was around 120 nGy/h, the exposure of the dosimeters between two read-outs did not exceed 20 nGy, which is far below the detection limit of the system. Therefore it can be stated that the background, and detection limit of the dosimeter system was measured with this method. The results of the measurement are presented in Table 2.

Table 2: Detection limit of the dosimeters.

Dosimeter ID	X0039	X0040	X0041	X0043	X0044	X0045
Detection Limit (µSv)	5.3	3.3	5.2	2.8	6.8	7.7

The radiation energy and angle of incidence dependence of the dosimeters was also measured according the IEC 61066 standard. The requirements of the standard prescribe that the measured and corrected average dose equivalents may not exceed the -29% - +67% range of the reference dose equivalent level in the energy range of N-100 X-ray radiation (83 keV average photon energy) to ^{60}Co (1250 keV). The dose conversion factor is a function of the angle of incidence and the radiation energy. Former measurements with Al_2O_3 TL material dosimeters have shown that the PorTL system easily fulfills these requirements on high energies; therefore we performed irradiation on lower X-ray energies and with ^{137}Cs source (662 keV) as reference. The dose $h_{pK}(10;N,\alpha)$ conversion coefficients used are presented in Table 3.

Table 3: The $h_{pK}(10;N,\alpha)$ dose conversion coefficients used during the experiment. The $H_p(10)$ personal dose equivalents are calculated from the 2 mGy air kerma and the dose conversion coefficients.

Radiation	**X-rax tube voltage [kV]**	**Mean photon energy [keV]**	**Angle of incidecce [°]**	**$h_{pK}(10;N,\alpha)$ [1]**	**$H_p(10)$ [μSv]**
Cs-137		662	0	1.20	2400
N-60	60	48	0	1.65	3300
			20	1.62	3240
			40	1.52	3040
			60	1.27	2540
N-80	80	65	0	1.88	3760
			20	1.86	3720
			40	1.76	3520
			60	1.50	3000
N-100	100	83	0	1.88	3760
			20	1.86	3720
			40	1.76	3520
			60	1.53	3060

Due to their geometry, there are two possible ways of rotating the dosimeters. For convenience, we will refer to the rotation directions as horizontal and vertical rotation as they are presented in Fig. 3. The positive and negative rotations (e.g. -40° and +40°) resulted nearly in the same effect.

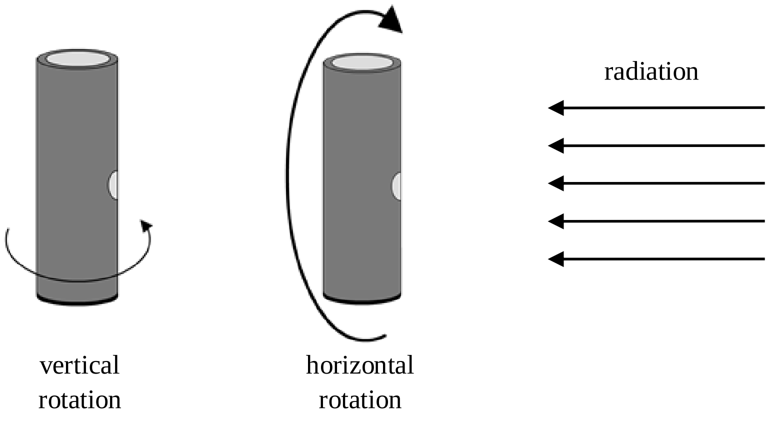

Fig. 3: Rotation directions

The dosimeters were irradiated on an ICRU slab phantom (Fig. 4) [2]. The dosimeters were rotated together with the phantom.

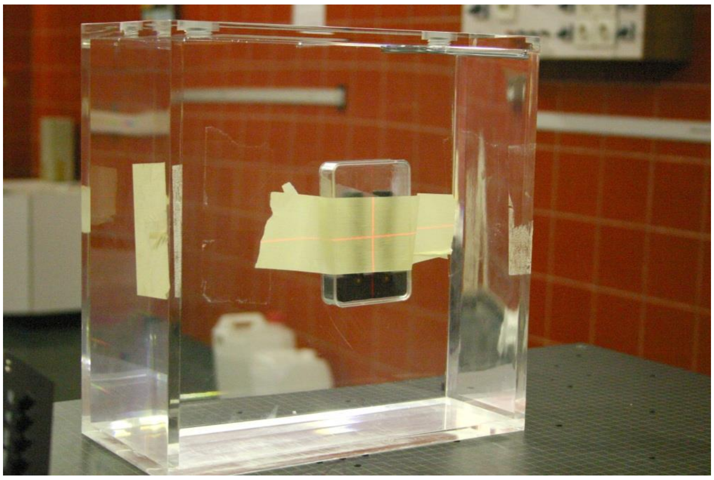

Fig. 4: Irradiation on ICRU slab phantom

After the N-60 X-ray irradiation all results were 50-60% below the reference dose equivalent level.

On N-80 X-ray energy the results were in the range of -29% to -17% of the reference level when the dosimeters were rotated in vertical direction. When they were rotated in horizontal direction, the results were in the range of -55% to -21% (Fig. 5).

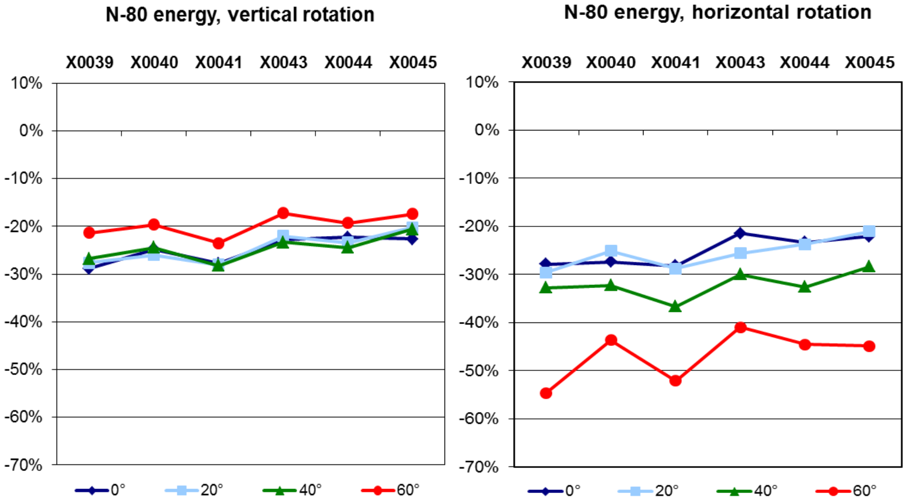

Fig. 5: Relative response measured on N-80 X-ray energy

On N-100 X-ray energy all results (both vertical and horizontal rotations) were in the range of -33% to +5% of the reference level (Fig. 6).

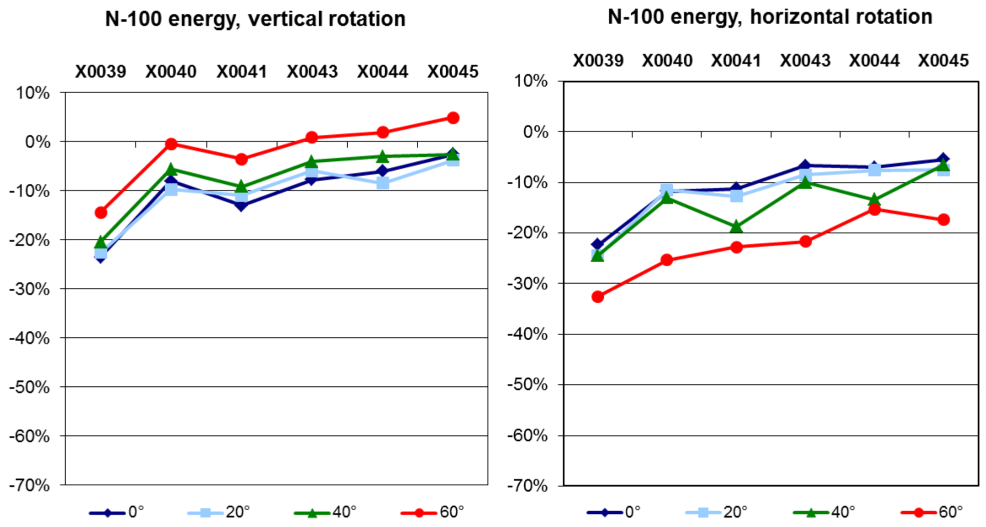

Fig. 6: Relative response measured on N-100 X-ray energy

Conclusion

The relative response due to radiation energy and the angle of incidence of the PorTL dosimeter system was investigated. The requirement of the IEC-61066 standard is that the relative response of the system should not exceed the range of -29% to +67% of the reference dose equivalent level between the energy of an N-100 X-ray and a ^{60}Co source. Considering the former measurements, the low energy ranges were investigated in the presented experiment.

At N-60 X-ray energy the PorTL system failed to fulfill the requirements.

At N-80 energy, the system has partially fulfilled the requirement. When the dosimeters were rotated vertically, the relative response was in the range of -29% to -17%. When the dosimeters were rotated in the horizontal direction, the response was lower than the requirement (-55% – -21%). This phenomenon can be explained with the geometry of the dosimeters: when the dosimeters are rotated horizontally, the shielding effect of the cylindrical cell of the dosimeters is increasing significantly with the angle of the rotation. This shielding effect is not affected by the vertical rotation of the dosimeter, since the rotation axis is identical to the axis of the dosimeter.

At N-100 X-ray energy all measurements were in the desired range – except one measuring point. The relative response of dosimeter X0039 was -33% when it was rotated by 60° horizontally. The average response of the six investigated dosimeters in this measurement point is -22%.

The experiments show that PorTL dosimeter system fulfills the requirements of the IEC-61066 International Standard on relative response due to radiation energy and the angle of incidence.

References

[1] IEC-61066 International Standard: Thermoluminescence dosimetry systems for personal and environmental monitoring; International Electrotechnical Commission; 1999

[2] ISO-4037-3 International Standard: Calibration of area and personal dosimeters and the measurement of their response as a function of energy and angle of incidence; International Organization for Standardization; 2006

[3] PorTL Dosimeter System Technical Description and User's Manual; *István Apáthy, Sándor Deme, Péter Szántó*; KFKI-AEKI-SKL-2006-366-01-02-0; 2006

[4] PorTL website; http://portl.kfki.hu