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TL and PTTL of TLD-100 and TLD-700 after irradiation with 14.5 MeV neutrons

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Abstract

In radiation dosimetry, phototransfered thermoluminescence (PTTL) found its use for dose reassessment. After the dose has first been evaluated by a normal thermoluminescence (TL) measurement, the same dosimeter is subjected to the PTTL dose reassessment procedure with the intention of obtaining a new estimation by a completely independent measurement procedure. Recently, some experimental data indicated that PTTL could be used as a tool for dose discrimination in a mixed field using single TL detector. In this work, the short overview of the use of LiF-based TL detectors in mixed field dosimetry is presented. In the experimental part, TL (main dosimetry peak and high-temperature peak (HTP)) and PTTL characteristics for TLD-100 and TLD-700 detectors were investigated for ^{137}Cs gamma rays and neutrons of 14.5 MeV. The results show that it is possible to determine separately gamma and neutron dose components with a single detector due to different sensitivities of TL and subsequent PTTL to neutrons in comparison to gamma rays.

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Keywords: Neutron dosimetry; Mixed field dosimetry; Thermoluminescence dosimeters; PTTL; TLD-100; TLD-700

1. Introduction

Personnel neutron dosimetry is performed for personnel working with neutrons in a wide range of situations since neutron sources are being widely used in medicine, industry, research and agriculture. Neutrons that are also produced in the atmosphere by cosmic rays add a small amount to the general exposure on the Earth surface, but the doses received by aircrews, which are classified as "occupationally exposed persons", deserve attention [1]. The measurement of neutrons aboard spacecraft remains one of the most important unmet challenges facing space radiation dosimetry. Due to the difficulty inherent in neutron dosimetry in a mixed field such as that encountered aboard spacecraft, it is not obvious how to solve this problem [2]. In addition, according to one estimation [3], practically 50% of neutron dose equivalent delivered at high altitude to commercial aviation personnel is delivered by neutrons with energies above 10 MeV. For these reasons there is a new interest for fast neutron dosimetry above 10 MeV energy.

Neutron dosimetry is generally mixed field dosimetry due to the fact that neutrons are usually accompanied by gamma rays. In such mixed fields thermoluminescent (TL) detectors are usually used for gamma ray dose measurements owing to their low sensitivity to neutrons. When LiF-based TLDs are concerned, their use is limited to detectors with Li enriched with ^{7}Li (^{6}Li has a very high cross-section to thermal neutrons that are practically always present in most of neutron fields).

The use of TL detectors for neutron dosimetry is mainly based on measuring albedo neutrons and in practical applications LiF-based TLDs are the most frequently used. The basic albedo dosimeter design consists of a pair ^{6}LiF and ^{7}LiF TLDs in different holder materials and constructions enabling the determination of gamma and neutron components of the dose separately. These dosimeters show high neutron energy dependence and wide variations with respect to detector-to-body distance and orientation. They

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require a very elaborate calibration in different neutron fields and are useful in neutron fields with moderated spectra. A detailed discussion of albedo personnel neutron dosimeters is given by Piesch and Burgkhardt [4]. Another approach to use LiF TL detectors doped with Mg and Ti (usually ^{7}LiF, TLD-700) for neutron dosimetry, the ‘‘two-peak method’’, is based on the fact that these detectors exhibit two glow peaks that have different sensitivities to low and high LET radiations. Since the intensity of the higher temperature glow peak is very small to be measured accurately and that it exhibits a very strong supralinear response to gamma rays, the use was limited to the cases when the gamma ray absorbed dose was only a few per cent of the total absorbed dose [5,6]. Closely related to the two-peak method is the glow curve superposition method, based on the whole shape of the glow curve responding differently to different components of the mixed radiation field. In mixed fields where the contributions to the total glow curve of either the photon or of the neutron dose is small, it seems that the glow curve superposition method provides better results than the two-peak method [7]. The property of TLD-700 that the net area under the deconvoluted high-temperature peak (HTP) increases with the average neutron energy is suggested as a technique for the estimation of the average neutron energy [8]. Another method, high temperature ratio (HTR) was developed in order to measure not only the absorbed dose but also to get information about the average LET. The HTR method compares the HTR of the glow curves obtained after irradiation in a mixed field with that obtained after ^{60}Co irradiation, normalised on the peak 5 (main dosimetric peak) maximum. Since this ratio correlates with the LET of the energy deposition, a LET calibration allows ‘‘the measurement of the average LET in mixed radiation fields’’ [9]. Measurements using HTR method have been carried out during various space missions and in an aircraft [9,10]. A similar method to estimate space radiation dose equivalent using an empirically adjusted combination of the relative TL efficiencies of peak 5 and the HT peaks as a function of LET (HTE method) has been proposed by Yasuda [11]. These latter two methods rely on a correlation of glow curve shape (glow peak relative intensities) with LET which, according to the critical review given by Horowitz et al. [12], has no theoretical justification.

The relatively new possibility for a separate dose determination in mixed fields as well as for a dose reassessment is based on phototransfered thermoluminescence (PTTL). Basically, the phenomenon of TL when excited by light (photostimulated thermoluminescence) has two aspects, photo-induced thermoluminescence (PITL) and PTTL. PTTL refers to TL induced by light as a result of photo transfer of charge carriers from one or more kind of traps to other kind of traps. Usually this transfer takes place from high-temperature (deep) traps that have been filled earlier by irradiation, to lower temperature (shallow) traps that have been emptied thermally, leaving the deep traps filled. PITL is TL directly induced by light in a fully annealed material [13]. Photostimulated TL has been found useful in the study of electronic processes, both PITL and PTTL have been tried for the measurements of ultraviolet radiation [14] and PTTL has been observed and studied for a wide variety of materials and its measurement has been suggested as a technique in radiation dosimetry and for dating ceramic artefacts [13,14].

In radiation dosimetry, PTTL has found its use for dose reassessment: after the dose has first been evaluated by a ‘‘normal’’ TL measurement, the same dosimeter is subjected to the PTTL dose reassessment with the intention of obtaining a new estimation by a completely independent measurement procedure [15]. Recently, some experimental data indicated that PTTL could be used as a tool for dose discrimination in a mixed field using single TL detector [16]. Majority of PTTL investigations have been done using UV illumination after gamma or beta irradiation. Only a few papers deal with heavy charged particles (^{241}Am alpha source [17]) and neutrons up to 5.9 MeV average energy [16–20].

In this work, TL and PTTL characteristics of TLD-100 and TLD-700, detectors were investigated for ^{137}Cs gamma rays and 14.5 MeV neutrons. The possibilities of using the difference in the sensitivities of both signals, PTTL and TL to neutrons, for the separate determination of gamma and neutron components of the dose for the two detectors are discussed. Also, TL results obtained in this work, namely the relative neutron sensitivities of the main dosimetric peak of TLD-100 and TLD-700 are compared with the previously published data. Instead of personal dose equivalent used in radiation protection practice, the quantity kerma (expressed as ‘‘tissue kerma’’) is used due to the fact that properties of the detectors were investigated performing ‘‘free-in-air’’ irradiations.

2. Experimental

TL detectors used were Harshaw LiF:Mg,Ti discs (4.5 mm diameter × 0.9 mm): TLD-100 (natural Li) and TLD-700 (isotope ^{7}Li). Both types of detectors were annealed in air at 400 °C for 1 h followed by 2 h annealing at 100 °C and ‘‘slow cooling’’ in the oven. After irradiation dosimeters stayed at room temperature for at least 1 day. Before reading, a 100 °C post-irradiation external annealing for 20 min was used. The reading of TL signal was carried out using a TOLEDO 654 reader (Pitman, England) with a new software developed, which enables an easier and more precise glow curve evaluation procedure [21]. The heating rate was 5 °C/s. The maximum reading temperature was 350 °C, chosen as a compromise–high temperature TL peaks are fully developed but PTTL is less pronounced (high-temperature deep traps are partly depopulated). The irradiated detectors were read twice, the second reading giving ‘‘the background’’ which is subtracted from the first reading in order to obtain the ‘‘net’’ TL (PTTL) glow curve of the dosimeter. For calibration and for determination of the individual