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An ultra-high dose of electron radiation response of Germanium Flat Fiber and TLD-100

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HIGHLIGHTS

- The supralinearity of GFF and TLD-100 was highly dependent on the UHD.
- The maximum supralinearity *f(D)max* of TLD-100, occurs around 10 kGy.
- TL kinetic model can be used to explain the glow peak behavior of doses < *f(D)max*.
- The supralinearity response decreases for doses above the critical dose limit.

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ABSTRACT

The thermoluminescence (TL) response of Germanium Flat Fiber (GFF) and TLD-100 irradiated with 2.5 MeV electrons for the doses up to 1 MGy were studied and compared. The aim was to evaluate the TL supralinearity response at an ultra-high dose (UHD) range and to investigate the change in kinetic parameters of the glow peaks, as the doses increases up to 1 MGy. It is found that the critical dose limit (CDL) of GFF is 5 times higher as compared to TLD-100. CDL is determined by the dose at the maximum supralinearity, $f(D)_{max}$. It is also found that annealing the TLD-100 and GFF with temperature more than 400 °C is required to reset it back to its original condition, following radiation doses up to 1 MGy. It is also noticed the strange behavior of Peak 4 (TLD-100), which tends to be invisible at the lower dose (< 10 kGy) and starts to be appeared at the critical dose limit of 10 kGy. This result might be an important clue to understand the behavior of TLD-100 at extremely high dose range. For both samples, it is observed that the TL intensity is not saturated within the UHD range studied.

1. Introduction

Thermoluminescence (TL) dosimetry at high dose radiation has attracted much attention as increasing needs in food safety, radiation protection on an extreme dose field and nuclear reactor dose monitoring. Therefore, it is crucial to reveal the performance of a dosimeter under circumstances of high dose deposition, and investigate the TL mechanisms, including the TL glow curve response and glow peak behavior, especially in the supralinearity dose response.

There are some findings from the Institute of Nuclear Physics (IFJ), Poland related to MTS-N which is equivalent to TLD-100 (IJF); (1) The TL response of TLD-100 (IJF) following high doses of ^{60}Co gamma rays revealed a new peak at the temperature of 420 °C for doses exceed 700 kGy by Khoury et al. (2011); (2) Bilski et al. (2010) found that two glow peaks dominated at 5 kGy with peak temperatures of 340 °C and 370 °C and saturated at 50 kGy; (3) A small peak was observed near 500 °C following irradiation of 20 kGy reported by Obryk et al. (2010) using 24 GeV/c protons. On the other hand, Montaño-Garcia and Gamboa-deBuen (2006) investigated the response of TLD-100 (Bicron) to high doses of ^{60}Co gamma rays and observed a significant increase in TL intensity of the peaks 5 and 7 within the range of 2.5 kGy to 7 kGy and then TL decreases with further increases in dose. Glow curves were deconvoluted into single first-order peaks using GlowFit®, a program developed by IFJ (Puchalska and Bilski, 2006).

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However, none of these works have adequately addressed the limitation of TL response at extremely high doses of electron radiation. Despite much excellent work on TL dosimetry such as dose linearity response and TL glow curve, scholars examining the TL behavior in the clinical dose range, have not yet fully explored the importance of supralinearity and critical dose limit, in an ultra-high dose radiation field. Yet, without such an understanding, we are left with an inadequate analysis that creates the condition for misinterpretation of the TL glow curve and main dosimetric peak evaluation and improper of kinetic model implementation.

This study will remedy this gap in the literature by examining the TL supralinearity response and determine the critical dose limit of GFF and TLD-100, in order to reveal more connections between the supralinearity behavior and the kinetic parameters of the specific high dose radiation field. The aim of this paper is to evaluate the TL glow curve response by using WinREMS® software and determine its kinetic parameters by using WinGCF® software deconvoluted glow peaks in the UHD region of interest.

2. Experimental procedure

The TLD-100 chips (3.0 mm × 3.0 mm × 0.89 mm) were obtained from the Harshaw-Bicron Company. The GFF samples used were fabricated with 6 wt% of Germanium dopant, by the Fiber Optic Research Center, Multimedia University, Malaysia. In this study, the samples were annealed using a Nabertherm Program Controlled S27 Furnace (Nabertherm®, Germany) at 400 °C for 1 h. At the end of the heat treatments, the samples were quickly cooled in air to the room temperature (RT) by placing them on an aluminum block. The cooling rate is estimated at 16 °C per minute.

The samples were irradiated with 2.5 MeV electrons at doses ranging from 1 kGy to 1 MGy at RT (ALURTRON®, Nuclear Malaysia Agency, Bangi, Malaysia). The TL yield as a function of temperature, referred to as the TL glow curve, were obtained by WinREMS®, which is the operating system for the Harshaw® TLD reader, model 3500 (Thermo Fisher Scientific Inc, U.S.A). During readout the following parameters were used: preheat temperature of 60 °C for 5.0 s; acquisition temperature of 400 °C for $116\frac{2}{3}$ s and a linear heating rate of 3 °C s^{-1}. All readings were taken under N_2 gas flow, to suppress oxidation and creating an isothermal contact between the sample and planchet. The temperature distribution inside the sample is assumed to be homogeneous. All TLDs were subjected to the homogeneity test with the method as described by Alawiah et al. (2015).

Samples were placed at a distance of 100 cm from the source, and irradiated in air with a beam width of 60 cm and the dose ranging from 1 kGy to 1 MGy. The irradiation process was carried out at an ambient temperature using accelerating voltage of 2.5 MeV and the beam current of 1.0 mA. Before the irradiation, the beam output was verified according to the dosimetry protocols of TRS 398 (IAEA, 2000). The measurement was carried out using an electrometer (Wellhofer, Scanditronix) with the cavity volume of 0.65 cm^3 (FC65-G) Farmer-type ion chamber. During the sample irradiation measurement, the delivered dose was separately measured by an ionization chamber to check the accuracy of the delivered dose.

Ten samples are allocated for one group of dose range and all samples were read for each TL measurement. A standard clean density glass filter was installed in the reader between the sample and photomultiplier tube, to eliminate unwanted infrared light emitted from the heater component. The samples were readout 24 h post-irradiation to minimize the low temperature peaks contribution in the glow curve. The glow curves were analyzed by a curve fitting computer program that is known as WinGCF® software, which then produce the deconvoluted glow peaks for the kinetic parameters evaluation. WinGCF® is the commercial software for the TL spectra data analysis. The computerized glow curve deconvolution (CGCD) is an established and a powerful tool for analyzing the TL glow curves and WinGCF® is mainly based on the first order kinetics equation (Randall and Wilkins, 1945).

3. Results and discussion

The experimental glow curves by WinREMS® and the deconvoluted glow peaks by WinGCF® are presented. The uncertainty of TL response has been determined as ±1 standard error of the mean and the coefficient variation did not exceed ±5%, as required for radiotherapy clinical applications (ICRU 24, 1976) and the homogeneity of the samples are maintained. The TLDs also show good reproducibility with a standard deviation less than 3.0%.

3.1. WinREMS glow curve analysis

As the TLD reader temperature continues to rise, the TL intensity increases until such time as the population of trapped electrons in the metastable state is sufficiently depleted at which point the TL intensity decreases with further increase in temperature. This will produce the characteristic of TL glow curve, for which consisting of the luminescence peaks in a plot of luminescence intensity versus temperature, as was illustrated schematically by WinREMs software.

As seen in Figs. 1 and 2, the experimental glow curve of TLD-100 consists of five peaks, whereas, there is only one peak for GFF, which are constructed by WinREMs application originally from the accumulated TL signal by the TLD reader.

The analyzed glow curves by WinREMS revealed that there are some significant changes in the TLD-100 glow-curve shape with increasing dose in the range of 1 kGy to 5 kGy. As shown in Fig. 1, there are only 4 glow peaks (glow peaks 5, 6, 7 and 8) visible in the overall temperature range of 60–400 °C. Glow peak 4 was not visible within the UHD dose range of 1 kGy to 5 kGy. All glow peak height showed high dependency on UHD by a factor of ~2.5 to 3. While, the glow curve of GFF remains constant, with one main peak at the temperature range of 250–350 °C, as the dose increases from 1 to 5 kGy.

As shown in Fig. 2, the GFF glow curve was found to be constant in shape, within this dose range. The main peak is located within the temperature range of 250–350 °C.

The TLD-100 of glow peak 4 starts to be visible at 10 kGy in the temperature range of 150–250 °C. Further increased of doses above 10 kGy, resulted on peak 5 to be diminished at a dose of 40 kGy (see Fig. 2) and clearly observed the appearance of the new high temperature peaks 7 and 8 in the temperature range of 250–400 °C.

Slight reduction in peak height was observed in glow peaks 5 and 6 while glow peaks 7 and 8 showed a significant increase in peak height by a factor of ~2. Interestingly, as the dose was increased to 40 kGy, glow peaks 5 and 6 were diminished while glow peaks 4, 7 and 8, remain visible, with a slight increase in their peak height. As shown in Figs. 1 and 2, glow peak 5 appears within the dose range of 1–10 kGy before being diminished with further increase of dose. The peak height of peak 5 was found to increase with increasing dose from 1 kGy to 4 kGy by 40% and then decrease by 43% with further increase of the dose up to 10 kGy.

This result was found to be in agreement with other research about peak height response with UHD which was done by Montaño-Garcia and Gamboa-deBuen (2006); they have evaluated the response of TLD-100 to high doses of ^{60}Co gamma rays up to