Applied Radiation and Isotopes 71 (2012) 30–34

Contents lists available at SciVerse ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Thermoluminescence in medical dosimetry

T. Rivera

Centro de Investigación en Ciencia Aplicada y Tecnología Avanzada-IPN, Av. Legaria 694, 11500 México, D.F., Mexico

HIGHLIGHTS

- ► Thermoluminescence (TL) in radiotherapy was proposed as routine dosimetry method.
- ► Patient skin dose distribution is determined by the TLD method.
- ► TLD is a good tool for treatment planning and quality assurance in radiation therapy.
- ► An integral dosimetry method (IDM) for medical dosimetry is proposed.

ARTICLE INFO

Available online 30 April 2012

Keywords:
Thermoluminescence
Radiation dosimetry
Ionizing radiation
TLDs
Medical dosimetry

ABSTRACT

Thermoluminescence dosimetry (TLD) is applied worldwide for personal and medical dosimetry. TLD method has resulted in many interesting findings in medicine as TL dosimeters have many relevant advantages such as high sensitivity, small physical size, tissue equivalence, etc. The main characteristics of various TL materials used in radiation measurements and their practical consequences are overviewed: well defined TL glow curve, batch homogeneity, signal stability after irradiation, precision and accuracy, response with dose, and influence of energy. In this paper a brief summary of the advances in the application of thermally stimulated luminescence (TSL) to dosimetry in radiation therapy application is presented.

1. Introduction

Thermally Stimulated Luminescence (TSL) or Thermoluminescence (TL) is the emission of light from an insulator or a semiconductor following the previous absorption from the source of exciting light energy, X-rays, or other ionizing radiation. The phenomenon of thermoluminescence (TL) may have been known as early as 1663 as empirically defined, when Sir Robert Boyle reported to the Royal Society about "experiments and considerations upon colours with observations on diamond that shines in the dark" (1663) and described how, upon warming of a diamond in contact with his body, he saw a luminescence in the dark (Daniels et al., 1953).

The importance of thermoluminescence for radiation dosimetry is due to the fact that the amount of light emitted is proportional to the absorbed dose by the irradiated material, which requires sensitive detection and accurate measurements of ionizing radiation. Under favourable conditions, emitted TL light intensity by a solid is proportional to the absorbed dose, and thus, using an appropriate calibration, one can evaluate the applied dose in the radiation field. Then, TL is an established method for radiation dosimetry as well as for retrospective dosimetry. The use of radiation dosimetry in medical practice is needed to optimize X-ray equipment and radiological techniques (Faulkner et al., 1999; NRPB, 1990). It is essential to assess radiation doses of patients in medical procedures to estimate the risk associated with the exposure. In diagnostic radiology such as X-ray examinations, nuclear medicine, CT scans, PET etc., this assessment is required both for the optimization of image quality, and radiation protection purposes. In radiotherapy the aim of the dosimetry is to make sure that the dose to the target volume is as prescribed while minimizing the dose to the surrounding normal tissue (the effectiveness of the treatment depends on delivering the dose with an accuracy of 5% or better in some situations) (ICRP, 1996). Thus one of the roles of thermoluminescent dosimetry in radiotherapy is to ensure the accurate delivery of dose to a tumour and at the same time plan the treatment so that the dose to healthy tissue is minimized. An active area of research is treatment optimization taking into account the almost infinite variety of treatment planning systems with the modern therapy accelerators using Monte Carlo Code Simulation Dosimetry (Azorín et al., 2010; Smith et al., 1995) as mathematical dosimetry system. Here mathematical dosimetry is predominantly a tool for quality assurance (QA), which is an important part of modern radiation therapy. QA ranges from a check of equipment performance to the

E-mail address: trivera@ipn.mx

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http://dx.doi.org/10.1016/j.apradiso.2012.04.018

investigation of new procedures. A QA procedure, which has been associated with TLD for many years, is in vivo dosimetry used directly on patients during a diagnostic or therapeutic procedure.

Traditionally, in radiotherapy, the absorbed dose distribution in a phantom must be measured to ensure that the prescribed adsorbed dose delivered to the target volume is necessary in the patient. Furthermore, while the measurement of absorbed dose distribution in a phantom is essential in treatment planning, the ultimate check on the absorbed dose delivered to the patient can only be made by in vivo absorbed dose measurements in the region of interest or in anatomical phantoms (Kron, 1995). The main objectives of dosimetry in medical dosimetry are typically phantom dosimetry and "in vivo" dosimetry which concern the determination of dose for patients during a medical treatment (Leunens et al., 1994). Thermoluminescent dosimetry (TLD) has been performed in order to be used for applications as different as radiation protection, radiotherapy, diagnostic radiology and quality assurance purposes such as calibration of treatment units, verification of computer programmes, validation of new protocols before clinical use, in vivo dosimetry either for particular techniques or to detect errors in individual patients (Noel et al., 1995). Application of luminescent dosimetry in these areas can be reported in the literature (Kron, 1995; Rudeń, 1976). In applications of thermoluminescent dosimetry (TLD) for problems related to medicine, it is important to measure the amount of radiation delivered (Ertl et al., 1997; Ginjaume et al., 1999). The aim of the present work is to summarize points of some requirements that may take place in thermoluminescent characteristics with radiation dosimetry to medical applications.

2. Principle of thermoluminescence dosimetry

Thermoluminescent dosimetry (TLD) is based on the ability of solids to absorb and store the energy of ionizing radiation, which upon heating is emitted in the form of electromagnetic radiation, mainly in the visible wavelength region. The light emitted is then detected and correlated to the absorbed dose received by the TL material. Many general theoretical models have been postulated to explain it, but even now difficulties arose when specific dosimetric materials are considered (Azorín, 1990; McKeever, 1985). One of the possible mechanisms for TL emission may be developed by considering the electronic band model (EBM) of the semiconductor (Fig. 1), considering three main elements as existing ones (e.g. recombination centres (RC), mobile carriers (MC) or charge carriers (CC), and traps (T)). Besides, the EBM assumes the existence of energy excited states in the forbidden band (FB) which play the role of traps or recombination centres. Ionizing radiation can supply the energy for creating the mobile carriers (electron and holes). The electrons are free to travel from the valence band (VB) to the conduction band (CB), meanwhile, the holes remain in the valence band or are free travelling near the VB. Due to the light emission process that involves the releasing of some traps at different energies, the mobile carriers are released at different temperatures giving rise to a glow curve which is characteristic of the material exhibiting one or more peaks.

This phenomenon is essential for radiation dosimetry due to the fact that the amount of light emitted is proportional to the dose absorbed by the irradiated material. Besides, it has been demonstrated that the integrated area under the glow curve between two temperature values (from room temperature to maximum temperature) is representative of the luminous energy released which is proportional or absorbed dose received by the TL material. Therefore, TL glow curve is often shown in the literature as the TL intensity as a function of temperature of the measurement cycle (McKeever et al., 1995). This feature is used by most of the TL readers in which the measurements are made based on total emission of one or more glow peaks. Then, the readout of a TL material is very simple and direct. In a relatively short time (in a few seconds or minutes), the material must be heated from an initial temperature in the range 50–100 °C up to a maximum temperature value as thermal history of the TL material under study at which it is adopted.

3. Characteristics of TLDs for medical dosimetry

Thermoluminescence (TL) phenomenon can be observed in many materials, however only a few of them fulfil the requirements for thermoluminescent dosimetry (TLD) (Portal, 1981). In Table 1 the requirements for medical dosimetry are shown. According to the recommendations of the International Atomic Energy Agency (IAEA) the uncertainty in medicine practice is associated with dosimetry measurements (IAEA et al., 2002). The contribution of medical dosimetry in radiation therapy has

Table 1
Requirements of TLDs for medical dosimetry.

Task	Dose range (mSv)	Uncertainty SD (%)	Tissue equivalent
Whole dosimetry	0.01–0.5	−30, +50	Important
Radiotherapy	0.1–100	±3.5	Very important
Diagnostic radiology	0.001–10	±3.5	Important

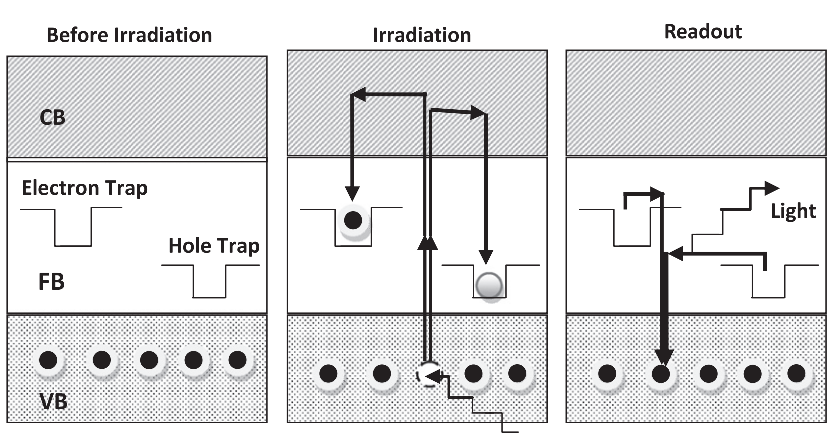

Fig. 1. The mechanism of thermoluminescent phenomenon.