Radiation Measurements 56 (2013) 200–204

Contents lists available at SciVerse ScienceDirect

Radiation Measurements

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

Characterization of OSL Al_2O_3:C droplets for medical dosimetry

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HIGHLIGHTS

- ► Droplets composed of thin powder of Al_2O_3:C were prepared using a photo-curable polymer.
- ► Powder grain sizes ranged from 5 to 35 μm.
- ► The droplets were characterized in calibration sources to be used as a basis of a 2D matrix detector.
- ► The droplets were exposed to different medical beam.

ARTICLE INFO

Article history:
Received 16 October 2012
Received in revised form
8 January 2013
Accepted 10 January 2013

Keywords:
OSL
Al_2O_3:C
Medical dosimetry

ABSTRACT

Radiation dosimetry for industrial and medical purposes has steadily evolved over the last few decades with the introduction of several new detectors. Al_2O_3:C (Akselrod et al., 1990) is a widely used Optically Stimulated Luminescence (OSL) material in gamma, x-ray and beta radiation dosimetry and, more recently, it has also been tested for particle therapy (Yukihara et al., 2010).

One advantage of this material is the capability of acquiring both dose rate and total dose, from two different phenomena observed in the Al_2O_3:C crystal: radioluminescence (RL) and optically stimulated luminescence (OSL), respectively. The possibility on having very thin Al_2O_3:C powder allows preparing droplets, which can be made with different volume concentrations and different sizes and can be used as basis for a 2D dosimetry system. In this article droplets were characterized using ^{60}Co, ^{137}Cs, ^{90}Sr/^{90}Y and electron and photon medical beams.

1. Introduction

Cancer is a global problem with high importance on the international health agenda because it affects millions in every country around the world. Tackling the problem requires significant resources. The international community has become aware that it is necessary to have better cooperation and coordinated efforts among all research centers, academia, governments and companies. The actual or potential use of the new advanced radiotherapy technologies raises many questions about their cost, efficacy and even ethics. Likewise, patient's safety must be assured and, for that, the precision and accuracy of modern radiation therapy relies to a large extend on robust and comprehensive dosimetry quality assurance and quality control. This includes beam calibration and characterization, verification of conformal dose distribution, identification of malfunction of equipment, or set-up errors. The use of Al_2O_3:C in medical dosimetry is still in its infancy, but keeps growing. High sensitivity detectors enable the readout of small-sized pellets. The high-resolution OSL dosimeters are particularly advantageous in regions of very steep dose gradients such as in hadron beams. Furthermore, the radioluminescence of Al_2O_3:C crystals coupled to optical fibers, can be readout in real time and are proportional to the dose rate (Andersen et al., 2006).

In this study, droplets were prepared in small volumes to be used as a basis of a 2D matrix detector, to measure dose with high spatial resolution.

In this paper we present the dosimetric properties of Al_2O_3:C droplets and compare them to the commercially available material Luxel™. Droplets consist of thin Al_2O_3:C powder mixed with a polymer insensitive to ionizing radiation.

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http://dx.doi.org/10.1016/j.radmeas.2013.01.048

2. Material and methods

2.1. Al_2O_3:C droplets and Luxel™

Droplets were prepared by mixing Al_2O_3:C crystal powder from Landauer Inc. (Stillwater, OK, USA) consisting of grain sizes between 5 and 35 μm with a photo-curable acrylic polymer (Klein et al., 2011):

The polymer hardens after being illuminated with a strong UVA light source (90 W) for 1 min. Previous studies have shown that this polymer does not demonstrate any OSL response and does not absorb light in the luminescence wavelength of Al_2O_3:C (Klein et al., 2011). The monomer mixture consists of the following components:

- 2 ml of Tetrahydrofurfuryl acrylate from Sigma Aldrich (408271).
- 3 ml of Di(trimethylolpropane) tetraacrylate from Sigma Aldrich (408360).
- 25 mg of 2-Hydroxy-2-methylpropiophenone 97% pure from Sigma Aldrich (40565-5), which is the UV photo-initiator.

Droplet samples with different powder concentrations and different volumes, were prepared. The results presented in this paper are related to droplets of 1 μl (concentration of 1 mg of powder per ml of polymer). These droplets measured approximately 2–3 mm in diameter and were 0.5 mm thick (Fig. 1b). Because of the presence of the polymer, droplets could not be annealed (heated to temperatures higher than 250 °C) to empty the trapping centers associated with the OSL signal. As an alternative, the material was bleached by illuminating it with light of an appropriate wavelength (green light with dominant wavelength at 505 nm and 4 cd – LED B3b-443-B505 from Daina Electronics Co., Ltd). In Fig. 1a the Al_2O_3:C white powder and colorless polymer is shown, and in Fig. 1b the droplets (smaller round samples) are compared to Luxel™ pellets.

Luxel™ pellets are round and thin detectors of 4.5 mm diameter cut out from a commercial Al_2O_3:C dosimetric tape from Landauer Inc. (Fig. 1b). The tape consists of Al_2O_3:C powder mixed with a polymeric binder and coated onto a roll of polyester film. The aluminum oxide layer is about 0.13 mm thick and is packed between polyester foils 0.05 mm thick (top) and 0.08 mm thick (bottom).

2.2. Risø TL/OSL reader and irradiations

OSL measurements and beta (^{90}Sr/^{90}Y with 126 ± 8 mGy s^{-1}) irradiations were performed using a Risø TL/OSL reader system, model TL/OSL-DA-20 (Botter-Jensen et al., 2000), equipped with a blue stimulation light source (470 nm), a bi-alkali EMI 9235QA photomultiplier tube and Hoya U-340 filters to block the blue light. The OSL readout procedure consisted in stimulating the dosimeters using the following protocol:

- Luxel™ pellets – LED 50% power for 600 s
- Droplets – LED 90% power for 600 s
- Calculation of the background (B) signal: average of the last 20 seconds-signal.
- Total integrated value: average of the 600 seconds-signal minus the background (Equation (1)).

$$T = \left[\sum_{t=1}^{600} S_t/600\right] - B \quad (1)$$

- Peak value: average of the first 2 s-signal minus the background (Equation (2)).

$$P = \left[\sum_{t=1}^{2} S_t/2\right] - B \quad (2)$$

Irradiations with 6, 9, 12, 16 and 20 MeV electrons and 6, 10, 15 and 18 MV photons beams were performed at the University Hospital Gasthuisberg (KU Leuven). More specifically, 6, 10 and 15 MV photon Clinical irradiations were performed on a linear accelerator Truebeam STx (Varian Medical Systems), 18 MV and electron irradiations were performed on a Clinac 2100 C/D (Varian Medical Systems). Irradiations with 6 and 12 MeV electrons and 6 and 15 photons beams were performed at the Ghent University Hospital, all with an Elekta Synergy.

In Leuven, photon irradiations were carried out with the pellets placed at the isocenter, below a stack of solid water slabs, at a depth of 10 cm, with a Source-to-Surface Distance (SSD) of 90 cm and a field size of 10 cm × 10 cm. The same reference position was used for beam calibration (which facilitates the conversion from beam monitor units to given dose). For electrons, the beam calibration was done with SSD = 100 cm and the samples were placed approximately at the depth of dose maximum (D_{max}) for each energy. In both cases, the dose rate was 6 Gy/min and total dose was 1 Gy. A similar beam set-up was used in Ghent university hospital, but the dose rates for the photon and electron beams were 5.5 Gy/min and 3.4 Gy/min, respectively.

^{137}Cs and ^{60}Co sources are available on the calibration laboratory from SCK·CEN. For our tests the dose rate of 1.2 Gy/h (for ^{60}Co) and 8.5 Gy/h (for ^{137}Cs) were used. Samples were irradiated on a phantom.

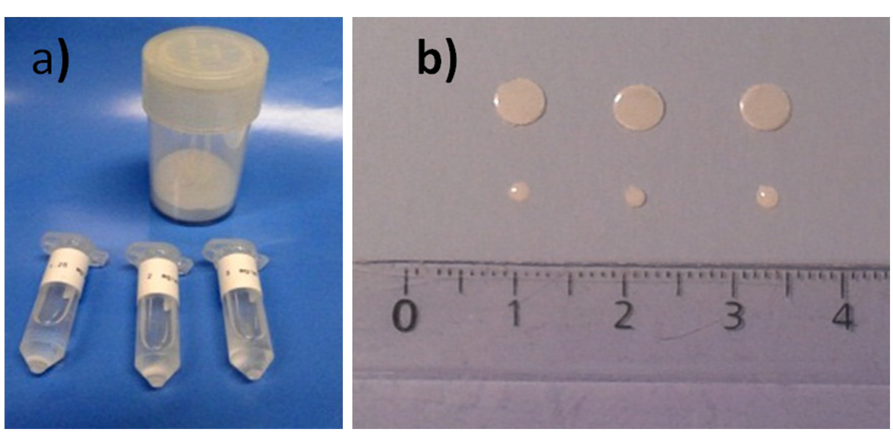

Fig. 1. a) Al_2O_3:C white powder and transparent polymer and b) droplets (lower samples) compared to Luxel™ pellets (bigger and upper samples).