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Note

Characterization of Al_2O_3 sintered pellets for dosimetric applications in radiotherapy

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Abstract. Al_2O_3 sintered pellets were tested in relation to their thermoluminescent properties, to investigate the possibility of their use for dosimetry in the radiotherapy cases of ^{60}Co and x-radiation. The material is inexpensive and has a glow peak at about 280 °C, a linear dose response between 0.1 and 100 Gy, suitable reproducibility and a low detection limit. The thermoluminescent response can easily be corrected for fading and the energy dependence, when necessary.

1. Introduction

The thermoluminescent (TL) properties of aluminium oxide (Al2O3) in different forms (pure and doped) have been investigated by several authors for radiation detection in recent years [1–7]. The studies showed that these materials exhibit linearity over a wide dose range, easy handling, high electrical and mechanical resistance and low cost, which can be used for a variety of dosimetric purposes, such as accidental and high-dose dosimetry [6, 8]. Summers [9] presented a review of the thermoluminescent glow curves in single-crystal samples of Al_2O_3 (alpha phase) over the temperature range from 10 to 700 K due to excitation with ultraviolet light, x-rays or gamma radiation. The results obtained showed that the ultraviolet sensitivity of the samples depends on the reduction/oxidation history of this material during the crystal growth.

Akselrod and Kortov [1] have investigated the thermoluminescent and exoemission properties of alpha-Al_2O_3:C crystals to determine the mechanisms of the electron–hole process and the possible use of this material for skin dosimetry. Osvay and Golder [6] studied the 'memory effect' of Al_2O_3 TL detectors in high exposure dosimetry to investigate dose re-estimation using the phototransferred thermoluminescence technique.

Aluminium oxide as a TL dosimeter has received the attention of several authors, and there is also a growing interest concerning the TL response of sintered and powdered alpha-Al_2O_3 samples.

This study involves the performance testing of calcined alumina powder (alpha phase), in the form of sintered pellets produced at a very low cost, to verify mainly the possibility of its use for the radiotherapy dosimetry of ^{60}Co radiation in laboratories with limited access to commercially available TLD materials.

2. Materials

Calcined alumina powder (alpha phase) produced by Alcoa (Poços de Caldas, MG, Brazil) was used to obtain sintered pellets of Al_2O_3 (8 mm diameter and 1 mm thickness). The impurity concentration of this material, determined at IPEN using the spectrographic technique, is shown in table 1, and it is different from the materials studied by Akselrod [1, 3] and Summers [9]. They were first cold pressed

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Table 1. Impurity concentration in Al_2O_3 sintered pellets.

Element	Concentration (μg g^{-1})
Cd	<1
Fe	<100
Cr	<10
Ni	<10
Zn	<50
Mn	<0.5
Mg	<10
Pb	<0.5
Sn	<2
Bi	<0.5
Cu	<1
Na	100
Ga	4
Sb	<5

Table 2. Specifications of the x-ray system of Instituto de Pesquisas Energéticas e Nucleares, São Paulo, Brazil.

Voltage (kV)	Current (mA)	Additional filtration (mm Al)	Half-value layer (mm Al)
25	30	0.44	0.26
30	30	0.54	0.37
40	30	0.68	0.56
45	25	0.73	0.65
50	25	1.02	0.91

and then sintered at 1650 °C (1 hour) to obtain the properties required for this study. These pellets were produced at the Ceramic Materials Department of IPEN. In order to determine the TL characteristics of the samples, they were irradiated under electronic equilibrium conditions, that is, the samples were placed between polymethyl methacrylate (Lucite) plates for ^{60}Co. The Al_2O_3 samples were tested using gamma radiation from a Telecobalt unit (Keleket Barnes Flexaray, model IS, 7.46 TBq), and x-radiation beams of two different systems: a Rigaku Denki generator, model Geigerflex, with Philips tube (60 kV) and Keleket therapy equipment (200 kV). In the latter case (intermediate energies), the irradiations were made at the ABC Radiotherapy Institute, Santo André, Brazil. The specifications of these systems are shown in tables 2 and 3. A polymethyl methacrylate (Lucite) phantom (30 × 30 × 15 cm) was used to determine the backscattering contribution.

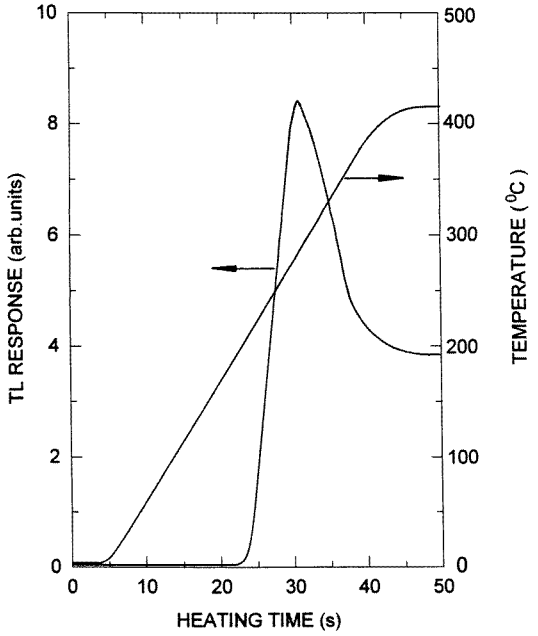

Figure 1. Thermoluminescence glow curve of an Al_2O_3 sintered pellet irradiated with 1.0 Gy (^{60}Co).

Prior to each irradiation, the samples were thermally treated at 400 °C (1 hour), a condition that was considered sufficient to eliminate previous exposures. The readout of the samples was made on a Harshaw Nuclear Systems Model 3000 TL Analyser, with a linear heating rate of 5 °C s^{-1}. The reading cycle was performed within 50 s, with a constant flux of N_2 of 4.0 l min^{-1}. The maximum temperature of 300 °C was reached in each readout cycle. The output data were recorded in an X–Y register (ECB (Equipamentos Científicos do Brasil), Brazil, model RB102, with two channels).

3. Results

3.1. Glow curve

Figure 1 shows the glow curve for an Al_2O_3 pellet irradiated with 1.0 Gy (^{60}Co). The main glow peak appears at about 280 °C.

3.2. Reproducibility

The reproducibility of the TL response of the Al_2O_3 pellets was obtained using ten pellets,

Table 3. Specifications of the x-ray system of the ABC Radiotherapy Institute, Santo André, Brazil.

Voltage (kV)	Current (mA)	Additional filtration (mm Al)	Additional filtration (mm Cu)	Half-value layer (mm Al)	Half-value layer (mm Cu)
100	13	—	—	1.90	—
120	13	1.00	—	2.70	—
140	13	1.00	—	3.20	—
200	13	1.00	0.50	—	0.90

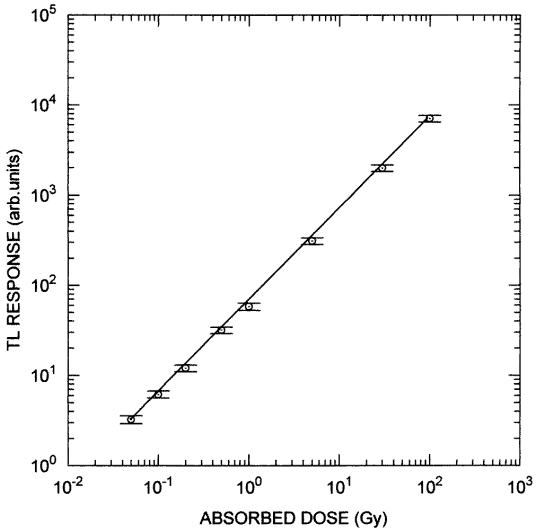

Figure 2. Thermoluminescence response of Al_2O_3 sintered pellets as a function of absorbed dose.

each one measured ten times after repeated procedures of a standard annealing and irradiation. The standard deviation of the TL response of each pellet, after ten readout cycles, was less than 3.9%. The pellets were irradiated with an absorbed dose of 1.0 Gy and then they were stored for 23 hours before being evaluated, to remove an unstable 77 °C TL peak from the glow curve.

3.3. Radiation dose response

The TL response of the Al_2O_3 pellets as a function of absorbed dose of ^{60}Co gamma radiation was measured and a linear dose response was obtained in the interval between 0.05 and 100 Gy. Data are shown in figure 2.

3.4. Lower limit of detection

The lowest detectable value was determined studying the variability of the signal obtained by the reading of non-irradiated pellets. It was taken as being equal to three standard deviations from the mean zero dose reading of the pellets. The lowest detectable value was 0.01 Gy.

3.5. Fading

The Al_2O_3 pellets were irradiated with an absorbed dose of 1.0 Gy (^{60}Co source), and then the fading at ambient temperature was studied for 90 days. The TL response showed initially a rapid decrease (25% after one day), then a much slower decrease after three days (1.5%).

3.6. Energy dependence

The energy response of the Al_2O_3 sintered pellets was studied for a range of x-ray energies, and the values were normalised to ^{60}Co. The TL response was measured from samples exposed to 1.0 Gy in x-radiation beams of 25, 30, 40, 45 and 50 kV (Rigaku Denki system) and 100, 120, 140 and 200 kV (Keleket system) in air and in front of the phantom. Figure 3 shows the energy response of the material. The maximum energy dependence was reached for an effective energy of 23 keV. The backscattering contribution to dose, due to the presence of the phantom, was also determined over the whole energy range tested. A maximum difference of 5.0% was found between the backscattering factors obtained in the present work and those of Jennings and Harrison [4] and Smith and Sutherland [10], as seen in table 4.

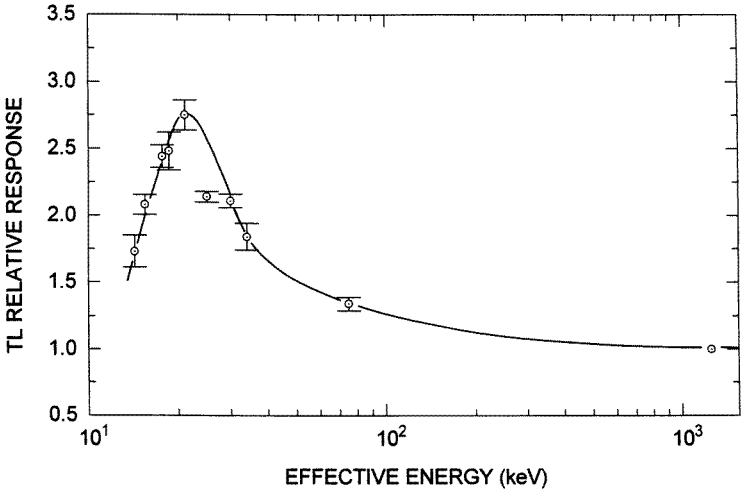

Figure 3. Energy response of TL Al_2O_3 sintered pellets, normalized to ^{60}Co.

Table 4. Backscattering factors (BSF) obtained in the present work in comparison with those of other authors.

Voltage (kV)	BSF (present work)	BSF [10, 11]	Difference (%)
100	1.27	1.24	3.0
120	1.20	1.26	5.0
140	1.29	1.27	1.6
200	1.31	1.33	1.5

4. Conclusion

The Al_2O_3 (alpha phase) pellets produced by IPEN have useful dosimetric properties, good mechanical resistance and very low cost. The results obtained indicate mainly the suitability of their use for field dosimetry at radiotherapy dose levels, after adequate corrections for fading, with a typical reproducibility of 4.0%, when commercial thermoluminescent dosemeters are not available.

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Résumé

En ce qui concerne leurs propriétés de thermoluminescence, on a contrôlé des pastilles frittées d'alumine (Al_2O_3), afin d'étudier leur utilisation dosimétrique possible, en radiothérapie par ^{60}Co et par rayons X. Ce matériau, peu coûteux, présente un pic luminescent à 280 °C environ, une réponse en dose linéaire de 0,1 Gy à 100 Gy, une reproductibilité correcte, une limite de détection plus basse. Il est aisé de corriger la réponse thermoluminescente de l'atténuation et de la variation de la réponse avec l'énergie, chaque fois que c'est nécessaire.

Zusammenfassung

Al_2O_3 Sinter-Pellets wurden hinsichtlich ihrer Thermolumineszenz-Eigenschaften getestet, um die Möglichkeit ihres Einsatzes für die Dosimetrie in der Strahlentherapie bei Verwendung von ^{60}Co und Röntgenstrahlung zu untersuchen. Das Material bietet niedrige Kosten, einen Glüh-Peak bei ca. 280 °C, eine lineare Dosis-Empfindlichkeit zwischen 0.1 und 100 Gy, angemessene Reproduzierbarkeit und eine niedrige Nachweisgrenze. Die Thermolumineszenz-Reaktion kann, falls erforderlich, problemlos hinsichtlich Fading und Energieabhängigkeit korrigiert werden.

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