PERGAMON

Available online at www.sciencedirect.com
SCIENCE DIRECT®

Applied Radiation and Isotopes 58 (2003) 719–722

Applied Radiation and Isotopes

www.elsevier.com/locate/apradiso

Thin sintered Al_2O_3 pellets as thermoluminescent dosimeters for the therapeutic dose range

Felícia D.G. Rocha, Mércia L. Oliveira, Linda V.E. Caldas*

Instituto de Pesquisas Energéticas e Nucleares, Comissão Nacional de Energia Nuclear, Caixa Postal 11049, CEP 05422-970 São Paulo, Brazil

Received 24 January 2003; received in revised form 4 April 2003; accepted 7 April 2003

Abstract

Thermoluminescent properties of sintered alumina pellets were investigated with the aim of using them as radiation dosimeters. Peak temperatures, signal reproducibility, fading, curves of the response to X-radiation, as well as energy and angular dependences were studied. The results show that the pellets can be used in quality control programs in the therapeutic dose range.

Keywords: Alumina; Aluminium oxide; Thermoluminescence; Dosimetry; Doses; Therapeutic

1. Introduction

Measurements of in vivo doses provide a reliable and effective way of checking the overall accuracy of the radiation treatment process (Edwards et al., 1997; Kron, 1999). The absorbed dose shall not deviate by more than 5.0% from the target value (International Atomic Energy Agency, 2000). In vivo dosimetry provides the doses actually absorbed by patients in treatment sessions, which helps detect and limit errors in the treatment procedures (Duch et al., 1998; Bartolotta et al., 1995). Thermoluminescent dosimeters (TLD) are very convenient for use, particularly in the procedures of radiation therapy (Belmonte et al., 2001; Weber et al., 2001; Essers and Mijnheer, 1999). Aluminum oxide is a promising alternative to the thermoluminescent materials currently used for in vivo dosimetry in quality control programs.

Natural and synthetic aluminium oxide (Al_2O_3) in its α form has been recently studied as a TL dosimetric material by several groups (Rocha et al., 2000; Rocha and Caldas, 1999; Kortov and Milman, 1996; Papin et al., 1996). The TL glow curves of pure α-Al_2O_3 feature four peaks between 50°C and 350°C (Papin et al., 1996), but the sensitivities, shapes and positions of the peaks depend on the impurity concentrations, the conditions of the crystal growth and the thermal treatment of the grown crystals (Tale et al., 1996). They can be used for measuring high doses at high temperatures (Molnár et al., 2001). The interest in alumina increased with the development of new materials on the basis of its structure, like α-Al_2O_3:C, which contain oxygen vacancies and provide a high TL sensitivity (Bos, 2001). Due to its low dose detection limit, alumina can also be used in environmental dosimetry, but its radiation sensitivity decreases with temperature in the +30°C to −100°C range (Molnár et al., 2001). Light-induced fading is probably the major disadvantage of this material in dosimetry (Duggan et al., 2000).

In this work, we investigated the thermoluminescence properties of sintered pellets made of low-cost Brazilian alumina (α form) in order to test the usefulness of this material for radiation dose measurements in the therapeutic dose range. The samples were irradiated in γ- and X-ray beams, and their main dosimetric characteristics (TL glow curve, signal reproducibility, fading, response curves, energy and angular responses) were studied.

*Corresponding author. Fax: +55-11-38169117.
E-mail address: lcaldas@ipen.br (L.V.E. Caldas).

0969-8043/03/$ - see front matter © 2003 Elsevier Science Ltd. All rights reserved.
doi:10.1016/S0969-8043(03)00117-9

2. Materials and methods

The calcinated α-alumina powder manufactured by Alcoa (Poços de Caldas, Brazil) was used to prepare thin sintered pure-Al_2O_3 pellets (0.8 mm thick and 5.5 mm in diameter). Concentrations of impurities in this material had been previously determined by Da Silva with semi-quantitative spectroscopy (Da Silva, 2001); they are listed in Table 1. The powder was initially cold-pressed and then sintered at 1650°C in air for 3 h to get the properties required for this study.

The alumina pellets were exposed to γ radiation from a ^{60}Co radioactive source (Gamma-cell, Model 220) under electronic equilibrium conditions in Lucite plates. X-ray irradiations were provided by two different systems: (a) Rigaku Denki generator, Model Geigerflex, with a Philips tube Model PW/2184/00 (Tungsten target and Beryllium widow, 60 kV), and (b) Pantak, Model HF 320 (Tungsten target and Beryllium window, 320 kV). Descriptions of these systems are given in Tables 2 and 3. Because of the light sensitivity (Duggan et al., 2000), the pellets were always wrapped into aluminium foil while irradiated.

The samples were heated for 60 min at 400°C before each irradiation. A Harshaw Nuclear System, Model 2000A/B, with a linear heating rate of 5°C/s was used as a TLD reader. TL readouts were performed within 75 s, with a constant flow of high purity nitrogen at the rate of 4.0 l/min. The integration areas between 50°C and 350°C were used. The output data were recorded with a two-channel x-t recorder ECB, model RB-101. The readings were always taken immediately after irradiations.

3. Results and discussion

3.1. Glow curve

Fig. 1 shows the TL glow curve of an α-Al_2O_3 sintered pellet irradiated to 10 Gy with X-rays (45 kV). The curve exhibits a very well defined dosimetric peak in the vicinity of 150°C. Similar observations were made by Springis et al. (1996) and Tale et al. (1996).

3.2. Reproducibility

The reproducibility of the TL response of the pellets was determined from 10 replicate measurements in repeated cycles of ^{60}Co irradiation and the standard annealing. The scatter of the results was less than 3.0%.

Table 1
Concentrations of impurities in the Alcoa pure Al_2O_3 (Da Silva, 2001)

Element	B	Si	Fe	Ga	Mg	Mn	Ca	Na
C (ppm)	4	120	30	30	300	5	350	100

Table 2
Specifications of the X-ray Rigaku Denki generator, Model Geigerflex, with Philips tube, Model PW/2184/00

Voltage (kV)	Half-value layer (mmAl)	Additional filtration (mmAl)	Effective energy (keV)	Air kerma rate (Gy/h)
25	0.26	0.45	14.3	23.59
40	0.53	0.68	17.7	34.40
45	0.65	0.73	18.7	32.71
50	0.91	1.02	21.2	27.29

Table 3
Specifications of the Pantak X-ray system, Model HF 320

Voltage (kV)	Half-value layer		Additional filtration		Effective energy (keV)	Air kerma rate (Gy/h)
	mmAl	mmCu	mmAl	mmCu		
100	3.76	—	1.21	—	37.9	5.00
135	—	0.47	—	0.23	66.0	4.81
180	—	0.95	—	0.48	82.2	6.76
250	—	2.39	—	1.57	143.2	6.82

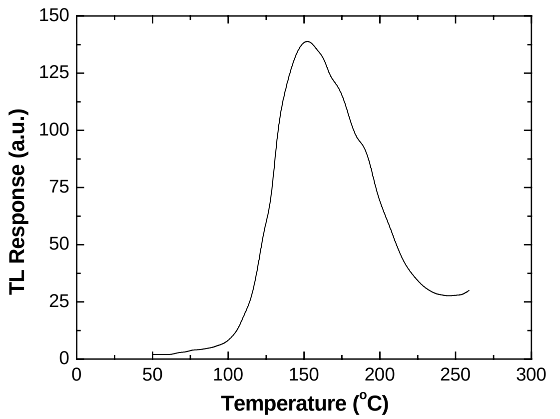

Fig. 1. TL glow curve of a sintered alumina pellet X-irradiated to 10 Gy.

3.3. Response fading

In this study, the pellets were irradiated to 50 mGy (^{60}Co) after being heated at 400°C for 1 h. The fading at the ambient temperature was monitored for 60 days. The TL response faded by about 6% in the first 3 h after irradiation. In the next 2 days, the response faded by only 1.5%, tending to a constant value. This fading should be taken into account in determining absorbed doses.

3.4. Calibration curve

The TL response of the pellets was plotted as a function of the absorbed dose of low- and medium-energy X-rays. In both cases, the TL response depends linearly on the dose, and the curves are useful in the whole tested dose range (Figs. 2 and 3).

In our previous work (Rocha et al., 2000), we studied the TL response of the same pellets to ^{60}Co γ radiation in the dose range from 0.01 to 100 Gy. No dose saturation was observed, and the response between 0.1 and 20 Gy was linear. The measurement uncertainties in those studies were always below 11%.

3.5. Lower limit of detection

The lowest absorbed dose detectable with the alumina pellets (1.0 mGy) was calculated from the variability of the TL readings of unirradiated pellets. It was taken as the dose that produces a response equal to three standard deviations of the bank readings.

3.6. Energy dependence

The dependence of the TL response on the energy of X-rays in the low- and medium-energy range is

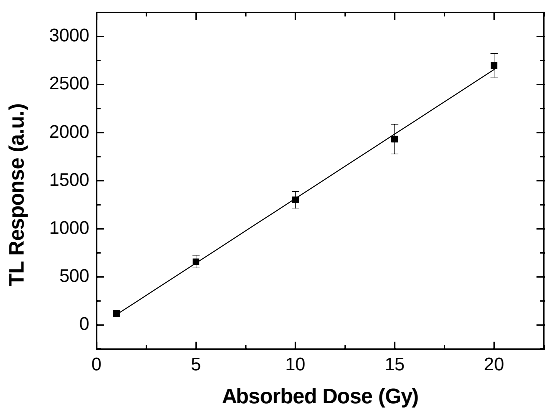

Fig. 2. TL response of sintered alumina pellets as a function of the absorbed dose of low-energy X-radiation. The uncertainties are within 10%.

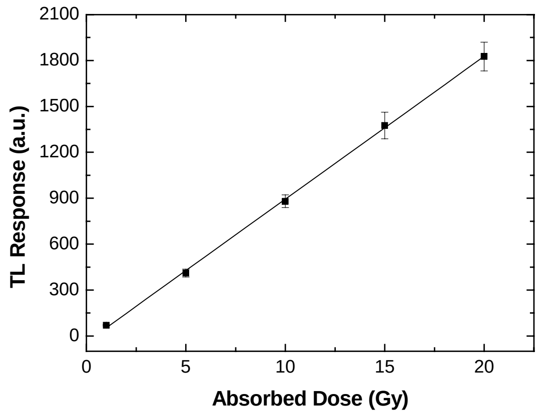

Fig. 3. TL response of sintered alumina pellets as a function of the absorbed dose of medium-energy X-radiation. The uncertainties are within 6%.

significant (Fig. 4) and should be taken into account in dose measurements.

3.7. Angular dependence

Fig. 5 shows how the TL response of the alumina pellets depends on the angle of incidence of X-rays. The maximal variation in the response in the tested angle range from 0° to 45° is just 2.5%, which makes the pellets useful for in vivo dosimetry.

4. Conclusions

The main dosimetric characteristics of sintered Al_2O_3 pellets, such as TL glow curve, response reproducibility, response fading, calibration curves, energy and angular dependences of the response, were determined. The

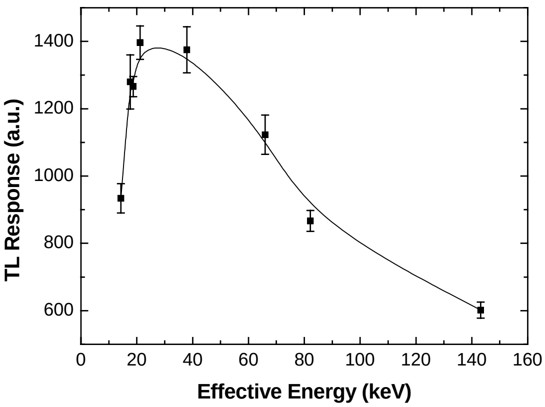

Fig. 4. Dependence of the TL response of sintered alumina pellets on the energy of X-rays. All the samples were irradiated to 10 Gy in air. The uncertainties are within 10%.

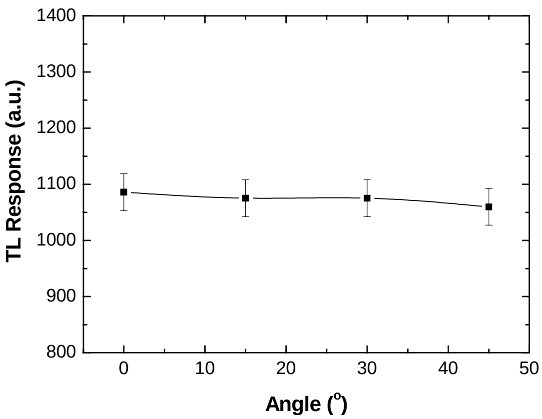

Fig. 5. Dependence of the TL response of sintered alumina pellets on the angle of incidence of X-rays. The uncertainties are within 3%.

results show that this material can be used in therapeutic dosimetry, provided that fading of its response is properly taken into account.

Acknowledgements

The authors are thankful to Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and to Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), Brazil, for partial financial support of this work.

References

Bartolotta, A., Brai, M., Caputo, V., Diliberto, R., Dimariano, D., Ferrara, G., Puccio, P., Santamaria, A.S., 1995. The response behaviour of LiF: Mg,Cu,P thermoluminescent dosimeters to high energy electron beams used in radiotherapy. Phys. Med. Biol. 40, 211–220.

Belmonte, A.D., Baraja, J.M.D., Manso, M.L., del Rio, J.R.S., 2001. Exit dose as a method to verify external radiotherapy treatments in vivo by TLD'S. Phys. Medica 17, 7–9.

Bos, A.J.J., 2001. High sensitivity thermoluminescence dosimetry. Nucl. Instrum. Methods Phys. Res. B. 184, 3–28.

Da Silva, M.R.O.O., 2001. Influence of microstructure and composition of sintered alumina on thermoluminescence for dosimetric applications. Dissertation (Master degree), University of São Paulo, São Paulo, Brazil (in Portuguese).

Duch, M.A., Ginjaume, M., Chakkor, H., Ortega, X., Jornet, N., Ribas, M., 1998. Thermoluminescent dosimetry applied to in vivo dose measurements for total body irradiations techniques. Radiother. Oncol. 47, 319–324.

Duggan, L., Budzanowski, M., Przegietka, K., Reitsema, N., Wong, J., Kron, T., 2000. The light sensitivity of thermoluminescent materials: LiF:Mg,Cu,P, LiF:Mg,Ti and Al_2O_3:C. Radiat. Meas. 32, 335–342.

Edwards, C.R., Grieveson, M.H., Mountford, P.J., Rolfe, P., 1997. A survey of current in vivo radiotherapy dosimetry practice. Br. J. Radiol. 70, 299–302.

Essers, M., Mijnheer, B.J., 1999. In vivo dosimetry during external photon beam radiotherapy. Int. J. Radiat. Oncol. Biol. Phys. 43, 245–259.

International Atomic Energy Agency, 2000. Absorbed dose determination in external beam radiotherapy: an international code of practice for dosimetry based on standards of absorbed dose to water. TRS 398, IAEA Publications, Austria, Vienna.

Kortov, V., Milman, I., 1996. Some new data on thermoluminescent properties of dosimetric α-Al_2O_3 crystals. Radiat. Prot. Dosim. 65, 179–184.

Kron, T., 1999. Applications of thermoluminescence dosimetry in medicine. Radiat. Prot. Dosim. 85, 333–340.

Molnár, G., Benebdesselam, M., Borossay, J., Lapraz, D., Iacconi, P., Akserold, M., 2001. Influence of the irradiation temperature on TL sensitivity of Al2O3:C. Radiat. Meas. 33, 619–623.

Papin, E., Grosseau, P., Guilhot, B., Benabdesselam, M., Iacconi, P., Lapraz, D., 1996. Influence of the calcination conditions on the thermoluminescence of pure and doped α-alumina powders. Radiat. Prot. Dosim. 65, 243–246.

Rocha, F.D.G., Caldas, L.V.E., 1999. Characterization of Al_2O_3 sintered pellets for dosimetric applications in radiotherapy. J. Radiol. Prot. 19, 51–55.

Rocha, F.D.G., Okuno, E., Caldas, L.V.E., Bressiani, J.C., Silva, M.O.O., 2000. Al_2O_3 sintered pellets for dosimetry at radiotherapy level. In: Proceedings of the International Congress of IRPA, Vol. 1. Hiroshima, pp. 351–353.

Springis, M., Kulis, P., Veispals, A., Tale, V., Tale, I., 1996. Origin of the 430 K TL peak in thermochemically reduced α-Al_2O_3. Radiat. Prot. Dosim. 65, 231–234.

Tale, I., Piters, T.M., Barboza-Flores, M., Salas-Perez, R., Aceves, R., Springis, M., 1996. Optical properties of complex anion vacancy centres and photo-excited electronic processes in anion defective α-Al_2O_3. Radiat. Prot. Dosim. 65, 235–238.

Weber, D.C., Nouet, P., Kurtz, J.M., Allal, A.S., 2001. Assessment of target dose delivery in anal cancer using in vivo thermoluminescent dosimetry. Radiother. Oncol. 59, 39–43.