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Enhanced sensitivity of alanine dosimeters to low-energy X-rays: Preliminary results

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Abstract

In this work, the response or sensitivity of L-alanine minidosimeters to low-energy photons was enhanced through the addition of iodine atoms in the form of KI, which is considered as a dopant. L-alanine minidosimeters with four different content of dopant (0%, 5%, 10%, 15%) were produced and irradiated with 30 Gy to X-ray beams of 80, 120, 250 kV and 10 MV. A ^{60}Co beam was also used for the normalization of the energy response. The EPR measurements were carried out using a K-Band (24 GHz) spectrometer. The results showed a maximum response around 40–50 keV for the doped minidosimeters. This maximum increases with the dopant content 2.2, 3.4 and 4.5 times for 5%, 10% and 15% KI, respectively, with respect to the response of the ^{60}Co irradiated undoped minidosimeter. This result can be explained by the presence of the iodine atom that would increase the probability of photoelectric absorption due to its K-absorption edge (~33 keV).

Keywords: L-alanine minidosimeter; K-band EPR; Dopant; KI; Low-energy photons; Photoelectron

1. Introduction

The effect of ionizing radiation after its interaction with the L-alanine molecule is the production of stable free radicals. Because the free radical is a paramagnetic species, it is susceptible to be detected by electron paramagnetic resonance (EPR) spectroscopy. The number of these radicals in irradiated alanine is directly correlated with its EPR signal intensity that in turn is proportional to the radiation dose and is taken as the dosimeter reading h (Fig. 1) (Regulla and Deffner, 1982).

The amount of free radicals produced will depend on the type of radiation (photons, electrons, protons, neutrons, alpha particles, heavy ions, etc.), the energy and the dose (Ebert et al., 1965). In addition, it is well known that the number N of radicals formed in alanine is expressed by (Rotblat and Simmons, 1962; Nelson, 2005)

$$N = N_\infty(1 - \mathrm{e}^{-KE}), \tag{1}$$

where N_∞ represents a saturation level, K is a constant related with the saturation behaviour and E is the total energy deposited by radiation in alanine. On the other hand, the radiation yield (radical production due to radiation) G is defined as the number of radicals produced per unit of absorbed energy (Nelson, 2005):

$$G = \frac{\mathrm{d}N}{\mathrm{d}E}. \tag{2}$$

The inverse of G $(1/G)$ will give the necessary energy to produce one free radical.

It was found in different reports that the G value for alanine varies between 0.9 and 7.7 depending on type and energy of radiation (Regulla and Deffner, 1982; Koizumi et al., 2003; Köhnlein and Müller, 1962; Sharaf and Hassan, 2004). We believe that this difference between the G values reported is due to the difficulty to accurately perform EPR quantitative measurements of the number of spins N in the sample (Poole, 1983; Mazur, 2006). The EPR signal intensity depends on several parameters, such as the cavity quality factor Q, filling factor, dielectric constant, humidity, effective microwave power in the sample, among others, and it is difficult to control all of them. Additionally, these measurements were performed at different laboratories with no intercomparison calibration among these spectrometers.

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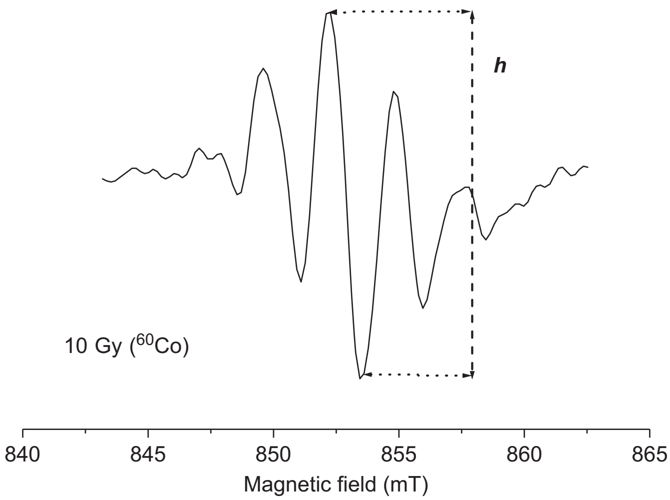

Fig. 1. K-Band EPR spectrum of L-alanine irradiated with Cobalt-60, showing the spectrum line used to express the free radical concentration produced by ionizing radiation.

On the other hand, it is known that alanine has an energy independent response for photon energies above 100 keV. For low-energy photons (< 100 keV) its response diminishes about 40% with respect to ^{60}Co energy (Regulla and Deffner, 1982; Alexandre et al., 1992; Zeng and McCaffrey, 2005).

In this work, preliminary results of the enhanced sensitivity through increasing the radical yield of alanine to low-energy X-rays with the addition of a doping in the dosimeter matrix are presented.

2. Materials and methods

2.1. Minidosimeters production process

Cylindrical pellets of 1 mm diameter and 3 mm length were produced by mechanical pressing of the powder dosimeter mixture. The mixture, consisting in L-alanine, a binder (PVA) and a dopant (KI), was prepared in water at 80 °C. After this, the solution was kept at this temperature until the water completely evaporated. Mixtures with four dopant weight concentrations (0%, 5%, 10% and 15%) were prepared resulting in decreasing L-alanine concentration (95%, 90%, 85% and 80%). The binder concentration was kept constant at 5%.

2.2. Minidosimeters irradiation

The four types of minidosimeters were irradiated with X-rays of different energies and with ^{60}Co. The beam specifications are shown in Table 1. For 80, 120 and 250 kV X-ray beams, a Siemens Stabiliphan 4 X-ray equipment was used. In the case of ^{60}Co, a radiotherapy unit Siemens Gammatron-S was used and a Mevatron Siemens linear accelerator was the source for 10 MV X-rays. For 80, 120 and 250 kV X-ray beams, the irradiation conditions were $10 \times 10\,\text{cm}^2$ field and 40 cm of source–surface distance (SSD) and without build-up cap. For the ^{60}Co beam, the conditions were $10 \times 10\,\text{cm}^2$, 80 cm of SSD and build-up of 5 mm. In the case of 10 MV beam, a field of $10 \times 10\,\text{cm}^2$, 100 cm of SSD and 2.2 cm of build-up were used. All irradiations were carried out at the Radiotherapy Service of HC-FMRP-USP. A unique dose of 30 Gy was given for all energies.

Table 1
Specifications for the photon beams used for the minidosimeters irradiation

Beam	Filtration	HVL	Effective energy
80 kV	2 mm Al	2.52 mm Al	32 keV
120 kV	4 mm Al	5.10 mm Al	43 keV
250 kV	0.8 mm Al 0.25 mm Cu 1 mm Al	3.16 mm Cu	145 keV
^{60}Co	–	–	1.25 MeV
10 MV	–	–	∼3 MeV

2.3. EPR measurements

The EPR spectra for all irradiated minidosimeters were recorded in the Department of Physics and Mathematics—FFCLRP-USP. A K-Band (24 GHz) spectrometer equipped with Bruker K-Band ER 067 KG microwave bridge and Bruker EPR Probehead K-Band cylindrical cavity with nominal unloaded Q of 15,000 was used. The other main parts of the spectrometer are a 12 in electromagnet (Varian), a magnetic field controller, a microwave digital frequency counter (HP) and a digital lock-in amplifier (EG&G). This equipment is controlled by a microcomputer via GPIB card. The data acquisition is made by software written in the HP-VEE platform. The spectrometer parameters used were: central field 852 mT, scanning field of 20 mT, modulation amplitude 0.2 mT, microwave power 0.63 mW, modulation frequency 100 kHz and microwave frequency 23.9 GHz. The K-Band quartz tube has an external diameter of 3 mm. The amplitude h of the spectrum, normalized by mass, was measured as function of the dose.

2.4. Determination of the minidosimeters energy dependence response

Cobalt-60 is used as the reference beam in radiation dosimetry. Thus, for alanine, the response for a particular photon energy E normalized to the ^{60}Co energy represents the energy dependence response and is expressed by (Zeng et al., 2004; Bergstrand et al., 2003)

$$r_E = \frac{(r_{\text{dosim}}/d_w)_E}{(r_{\text{dosim}}/d_w)_{^{60}\text{Co}}}, \tag{3}$$

where r_{dosim} represents the EPR signal intensity (h) divided by the minidosimeter mass and d_w is the radiation dose (30 Gy).

3. Results and discussion

Examples of some EPR signals for the minidosimeters irradiated to different photon energies are shown in Fig. 2.