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Physico-chemical studies for strontium sulfate radiation dosimeter

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ABSTRACT

Anhydrous strontium sulfate ($SrSO_4$) has shown a promise candidate as a dosimeter for low dose applications producing unique EPR signals with γ-rays which it has a linear response relationship ($r^2 = 0.999$) in the range of 1–100 Gy. The present study extended to evaluate the properties of strontium sulfate dosimeter in intermediate dose range of technology applications. It was observed that the intensity of the EPR signal at $g = 2.01081$ increases with a 3rd polynomial function in the range of 0.10–15 kGy. In addition, the radical (SO_4^-) provides a stable signal with a good reproducibility (0.107%). Other physics characteristic including the collision of mass stopping power dependence of the system and the effect of atomic number in different energy regions were investigated. The uncertainty budget for high doses has obtained from the measurement with value of 3.57% at 2σ confidence level.

1. Introduction

In spite of its birth more than 55 years ago, EPR dosimetry still has to prove itself in industrial radiation applications and other clinical and medical applications Morrissey and Prokopenko (1993). The advantages using of solid-state/EPR dosimetry are due to the high sensitivity and large dynamic range. Signal to noise ratio (S/N) appears in measurements can be improved by repeated reading of the sample Ikeya (1993a, 1993b), in addition it has the ability to repeat measurements and thus allowing storage for archival purposes Yordanov and Gancheva (2004).

EPR signals can be achieved when unpaired electrons occur at defects in solids or can be obtained by irradiation of the solid material with photons or particles giving opportunity for the formation of free radicals due to a break of chemical bonds Juárez-Calderón, Negrón-Mendoza, Gómez-Vidales, and Ramos-Bernal (2009).

Strontium sulfate/EPR dosimeter is examined Rushdi, Abdel-Fattah, Sherif, Soliman, and Mansour (2014) and shown its ability to control the low absorbed dose in the range of 1–100 Gy. The radical introduced as dosimetric signal is SO_4^-: This radical has an isotropic g-value giving rise to a narrow EPR signal. The aim of this work is an effort to evaluate the dosimeter potential to be used in intermediate dose range including post irradiation stability and dose response to ^{60}Co gamma irradiation. In other hand, additional studies were done including, the collision of mass stopping power

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dependence of the system, the effective of atomic number (Z_{eff}) at different energy regions and the radiation efficiency (number of free radicals per 100 eV of radiation, G-value). The uncertainty budget for intermediate dose range has been estimated from the measurements and compared to the value obtained in low dose range. The investigation of the properties has been compared to L-alanine as a reference standard dosimeter.

2. Materials and experimental technique

2.1. Materials and irradiation

Strontium sulfate rods was prepared from a reagent grade powder of strontium sulfate (97%, molecular weight, 183.68, from Qualikems Fine Chemicals Pvt. Ltd., New Delhi) mixed with ethylene vinyl acetate copolymer – EVA (TEC-Bond 232/12, Power Adhesives Limited, England) and paraffin wax (Congealing point 65–71 °C, BDH) which they were selected as binding materials. This binder was successfully used in previous preparations of rod dosimeters (Abdel-Fattah, El-Din, & Abdel-Rehim, 2004; Soliman & Abdel-Fattah, 2012). It does not present any interferences or noises in the EPR signal (Abdel-Fattah et al., 2004). The mixture was stirred mechanically at 2000 rpm before pulling by special PP sticks in order to achieve a homogenous form of rods.

Three different rod batches of 26%, 36% and 46% $SrSO_4$ by weight are prepared and stored in the dark at room temperature for further dosimetric investigations. The average weights of the prepared rods are 0.203 ± 0.002 g, 0.225 ± 0.002 g and 0.248 ± 0.003 g, respectively.

The rod dosimeters were irradiated by ^{60}Co source at National Center for Radiation Research and Technology (NCRRT) having a dose rate of 1.73 kGy/h.

2.2. EPR spectrometer and measurements

The EPR spectra for strontium sulfate rod dosimeters were recorded at room temperature on a Bruker, EMX EPR spectrometer supplied with 9.5 GHz microwave (X-band) and a rectangular cavity of ER 4102. Each rod was measured twice rotating (0° and 90°) by changing the position of samples in the cavity. The signal intensity was measured as peak to peak of the first derivative of the absorption spectrum. The readout parameters for $SrSO_4$ in comparison to alanine dosimeter were as follows (Table 1).

A DPPH (α, α-diphenyl-β-picrylhydrazyl) was used to adjust the EPR spectrometer stability and to correlate the peak height (PH) of dosimeter to the PH of DPPH. The dose–response of the dosimeter was plotted in terms of correlated PH ($PH_{dosimeter}/PH_{DPPH}$ × weight of the rod, g) against absorbed dose.

Table 1 – The readout parameters for $SrSO_4$ in comparison to alanine dosimeter were as follows.

Parameters	Alanine	Strontium sulfate
Receiver gain	$7.69*10^3$	$3.99*10^2$
Microwave power (mW)	2.007	3.188
Modulation amplitude (mT)	0.5	0.4
Center field (mT)	345.61	345.168
Sweep width (mT)	20	12

3. Results and discussion

3.1. EPR spectra and power dependence

Fig. 1 shows the EPR spectrum of photon irradiated strontium sulfate, it contains 5 peaks correspond to $g = 2.01081$, 2.04225, 2.03166, 2.00774 and 1.9219086. The intensity of radiation-induced EPR signal of $SrSO_4$ at $g = 2.01081$ (SO_4^{2-}) was used as dosimetric signal Rushdi et al. (2014) followed as a function of gamma dose in the intermediate dose range. The EPR spectra of 5, 10 and 15 kGy dosimeter rods of $SrSO_4$ at room temperature increase significantly with the increase of absorbed dose. It exhibit a narrow EPR signal with line-width of 0.3502 mT, does not change with dose compared to alanine EPR dosimetric signal ($\Delta H = 0.604$ mT). EPR signal intensity is proportional to the square root of the microwave power, it can be seen from (Fig. 2) that, the intensity of ($g = 2.01081$) signal increases and produce broadening EPR lines with increasing of the microwave power value. The microwave power is usually lifted above the linear region in order to improve the S/N-ratio Olsson, Bagherian, Lund, Alm Carlsson, and Lund (1999). At very low powers the signal shape deformed and/or completely lost. Best selection goes to the value of 3.81 mW which it kept in the linear region and has low-noise characteristics.

3.2. Dose response and spin concentration

Fig. 3 illustrates the dose response functions for the rod dosimeters of 26%, 36% and 46% $SrSO_4$ irradiated up to 15 kGy. The intensity of the signal increases with increasing absorbed dose by a third polynomial regression function (correlation coefficient, r^2 0.999). The selected function with higher r^2 confirms the validity of the dosimeter for dose process control and the reproducibility of EPR signal measurements.

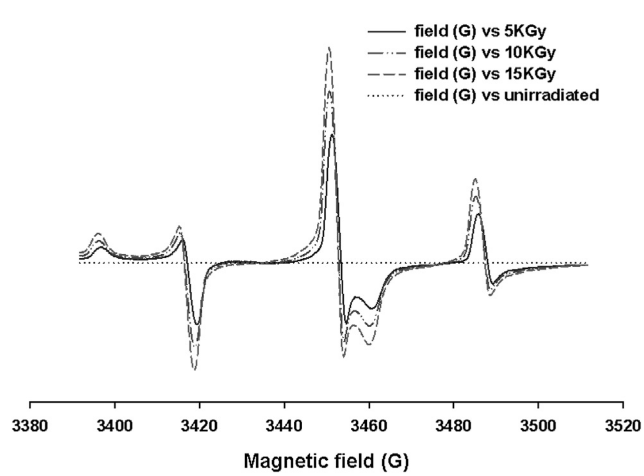

Fig. 1 – EPR spectra of unirradiated and γ-irradiated $SrSO_4$ dosimeters (5, 10, 15 kGy) of 26% concentration.