

Alanine dosimetry of 60 MeV proton beam – preliminary results

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Abstract. Electron paramagnetic resonance (EPR) spectrometry (X-band) was used to determine the dose absorbed in alanine detectors, of different shapes and different alanine content, irradiated with Co-60 gamma rays and in a 60 MeV proton beam. The goal of our study was to confirm applicability of alanine as a passive detector in therapeutic proton beam. In the paper dose response characteristic and relative efficiency of alanine are shown. The study confirmed that alanine detectors with a high alanine content (ca. 95%) may be a useful and convenient tool for dose measurements in proton beams, used for eye cancer treatment.

Key words: alanine • dosimetry • electron paramagnetic resonance (EPR) • proton beam

Introduction

Electron paramagnetic resonance spectrometry (EPR) of the amino acid L- α alanine $\text{CH}_3\text{-CH}(\text{NH}_2)\text{-COOH}$, used as a radiation sensitive material, has been known as a dosimetry method for over 40 years. EPR dosimetry has been applied mainly for high dose measurements in food preservation and medical equipment sterilization [2, 13]. Upon the interaction between ionizing radiation and L- α alanine, here referred to as alanine, paramagnetic centres in the form of stable free radicals are formed. Their number is proportional to the absorbed dose. The main effect of alanine irradiation is the production of $\text{CH}_3\text{-}\dot{\text{C}}\text{H-COOH}$ free radicals, however production of other species is also reported [14]. The concentration of paramagnetic centers in alanine samples is easily measurable by EPR technique. In the last years EPR/alanine dosimetry has gained attention as a potential tool in radiotherapy for proton and other ions dosimetry. The composition of the alanine detectors is similar to that of a tissue. Moreover, alanine detectors show linear response¹⁾ to dose and high sensitivity²⁾ [11]. The goal of the present study was to measure the response of alanine detectors to the proton beam with initial energy of 60 MeV. Detectors with different alanine content and different shape were studied. Characterization of proton dose response of alanine detectors at different proton energies is important in

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¹⁾ Response of alanine detector is defined as a peak-to-peak amplitude of the central line in the alanine EPR spectrum. It is proportional to the amount of the radiation induced radicals or absorbed dose [15].

²⁾ Sensitivity of alanine detector depends on the number of free radicals formed in the detector volume per unit absorbed dose.

order to determine applicability of alanine-based solid state detectors in proton and other ions dosimetry.

Materials and methods

Alanine detectors

The alanine-based solid state dosimeters used in the present study were in the form of cylindrical pellets and thin alanine films. The alanine pellets, 4.9 mm in diameter, 10.5 mm thick, contain about 95% alanine. Such high alanine content makes them sensitive to the radiation in therapeutic dose ranges. The alanine films (0.25 mm thick) consist of alanine microcrystalline and polyethylene-vinyl-acetate powders, 30 and 70% weight ratio, respectively [7]. The lower alanine/binder ratio makes them less sensitive than pellets, however they are very suitable for measurements, where a high spatial resolution is required.

Irradiations

For calibration purpose, both pellets and films were irradiated with a Co-60 source, Theratron 780E, at the Henryk Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences (IFJ PAN) in Kraków, Poland. The uncertainty of dose delivery, resulting from the precision of dose measurement with Markus chamber, was up to 3%.

Irradiations in a modulated and unmodulated 60 MeV proton beam were performed at an IFJ PAN facility for ocular tumor treatment. The reference dosimetry for proton irradiations was also performed with a Markus type parallel plate chamber, calibrated in a Co-60 field following the TRS-398 code of practice [5].

Alanine pellets were irradiated with eight doses (1, 2, 5, 10, 20, 30, 50 and 70 Gy), in the middle of the spread-out Bragg peak (full modulation), which is the reference position for therapeutic dose measurement [5]. Five detectors were irradiated at each dose point.

The alanine films were irradiated in sheets (1.2 × 1.2 cm), in the raw Bragg curve.

The first irradiation, with the purpose of film response investigation, were performed at the plateau of the Bragg curve. The films were irradiated with four dose values (250, 500, 1000, 1500 Gy), a single sheet (converted then to a detector – see below) at each dose point. During the next irradiations, aimed at relative efficiency investigation, the films were placed at different depths in the Bragg curve. Proton entrance energies at each measurement point were simulated with SRIM program and Monte Carlo calculations with MCNPX codes.

EPR measurements

The EPR measurements were carried out at room temperature in X band, at approximately 9.6 GHz. The spectra have been recorded with a Bruker ESP 300E spectrometer. A wide range of microwave powers and modulation amplitudes were tested in order to

optimize the detection conditions. Finally, the following parameters, recommended also by ISO/WD 15566.1 [6], have been chosen: modulation amplitude 1 mT, microwave power 8 mW, centre field 343 mT, sweep width 2 mT (measurements of the central line only), sweep time 20 s, time constant 320 ms, number of sweeps 3. The peak-to-peak amplitude of the central line of the spectrum, normalized to that of a reference sample, was used as a dosimetric quantity.

Commercially available alanine pellets used in the present study were brand ready for measurements with an EPR spectrometer and they did not require any “pretreatment”.

Five successive read-outs of each pellet were performed. Between the consecutive read-outs the detector was repositioned. The mean of the signal amplitude was used to estimate the dose.

The alanine films were treated before read-outs in the EPR spectrometer as described in the paper by Onori *et al.* [12]. In order to reduce the variation of EPR signal connected with anisotropy effect (therefore independent of dose), as well as in order to suite the detector shape and size to a quartz tube placed inside the resonance cavity of the spectrometer, alanine sheets were cut into disks of diameter 4.9 mm each. One detector consisted of four disks. The disks were piled up in a stuck form in the quartz tube. Each detector was read out five times. Between the consecutive read-outs, the detector was repositioned and disks were taken out of the tube and randomly reinserted. The mean of the peak-to-peak amplitude was used for dose estimation.

Results and discussion

Proton dose response characteristics. Alanine pellets

In the present study the linearity of proton dose response of alanine pellets was tested in the range of 1–70 Gy, which corresponds with a dose range applied in the proton radiotherapy of eye melanoma. EPR signal of alanine pellets in the function of the proton dose measured by the Markus chamber is shown in Fig. 1.

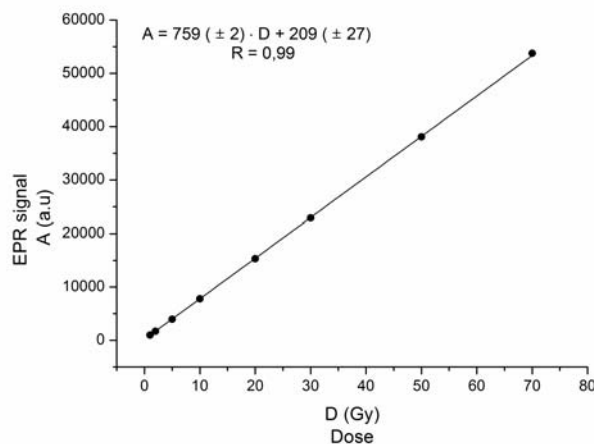


Fig. 1. The alanine pellets EPR response vs. the Markus chamber proton dose. Calibration curve fitted with the least squares method. The experimental uncertainties are within the symbol size.

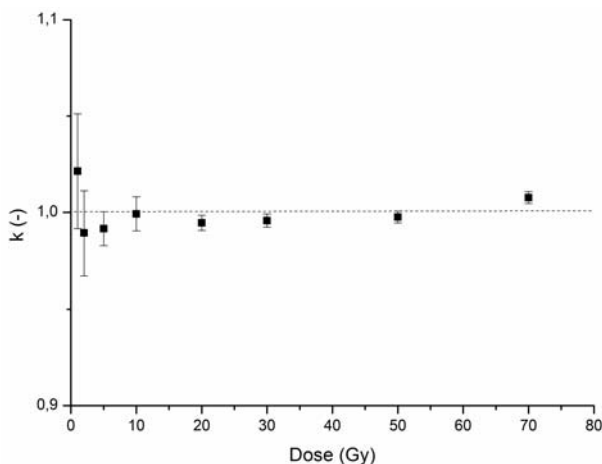


Fig. 2. The alanine pellets. The deviation of registered dosimetric signal from the predicted values, calculated from the calibration curve.

Alanine pellets' response to the increasing dose is linear, as the one-hit detector model predicts [9, 16]. The calibration curve was fitted with the least-squares method. Figure 2 shows the deviation of measured dosimetric signal (A_m) from the predicted value, calculated from the calibration curve (A_c), expressed as:

$$(1) \quad k = A_m/A_c$$

Uncertainties of k value are the largest for the doses of 1 and 2 Gy. These dose values are usually reported as a lower limit of detection of alanine detectors, characterized by a similar size and alanine content as the alanine pellets used in the present work [8].

Characteristics of proton dose response. Alanine films

Thin alanine films are characterized by a low alanine/binder ratio which makes them much less sensitive to the radiation than alanine pellets. The dose detection limit for the films, determined in the present study, was at the level of 150 Gy. A good quality, reproducible signal was registered for a dose of 250 Gy. This dose range is not used in the clinical practice. Therefore, alanine films are used only in the basic research, where a high spatial

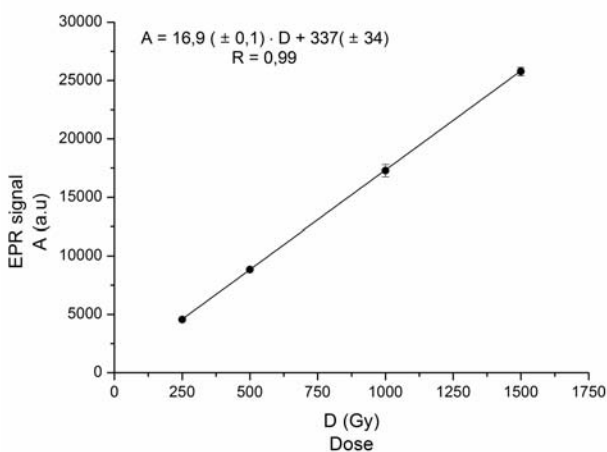


Fig. 3. The calibration curve for alanine films fitted with the least squares method.

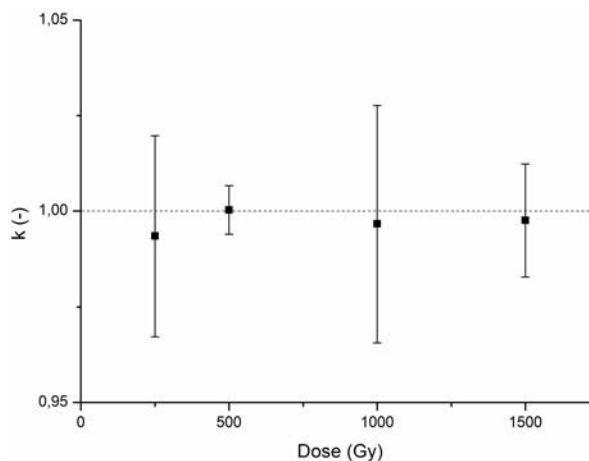


Fig. 4. The alanine films. The deviation of registered dosimetric signal from the predicted values, calculated from the calibration curve.

resolution of measurements, with the desired thickness of detector of 0.25 mm, is required. The procedure of preparing a detector from the irradiated alanine sheets and the read-out procedure are described in the section 'Materials and methods'. Figure 3 shows the alanine films EPR response vs. the Markus chamber proton dose, which is linear (the least-squares method fit). Figure 4 presents the k values for alanine films.

Relative effectiveness

The dose response of an alanine detector shows the dependence on proton energy [4, 10]. This fact must be taken into consideration in clinical secondary dosimetry based on alanine. For this reason, the response of alanine detectors in different regions of the raw Bragg curve was carefully investigated. The relative efficiency, η , is the most commonly used quantity describing the change of the dose response of the detector with particle energy. It is defined as the detector response per unit dose of investigated radiation, normalized to the response for dose of a standard gamma radiation [9]. The measurements of alanine relative efficiency were performed with alanine films, in selected points of a raw Bragg curve, corresponding to the different entrance energies of protons. A good spatial resolution provided with thin alanine films was indispensable in this case, because the proton energy decreases successively along the Bragg curve, with a strong and steep gradient in the peak region. The thickness of detector (0.25 mm) was smaller than the range of protons in the detector material for proton energies above 4 MeV (SRIM calculations). The relative efficiency of alanine to different proton energies (Fig. 5) is shown as a function of mean proton energy deposited in the detector volume. The η uncertainty was estimated considering propagation of uncertainties connected with EPR signal read-out, long term stability of spectrometer, nominal dose delivery and detectors mass normalization.

The η values obtained in the present study are compared to the values measured by other authors [1, 3, 4, 10, 12] as well as to some theoretical model predictions [9, 16]. The relative efficiency of alanine reported in the pres-

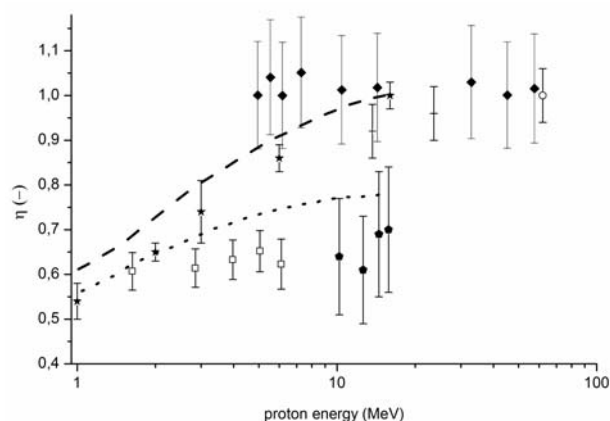


Fig. 5. Relative effectiveness (η) values obtained for alanine films (\blacklozenge). For comparison relative effectiveness values obtained by other authors. Experimental data: Olsen and Hansen (\star) [10], Ebert *et al.* (\bullet) [3], Bartolotta *et al.* ($+$) [1], Onori *et al.* (\circ) [12], Fattibene *et al.* (\square) [4]. Calculations: Olko (dashed line) [9], Waligorski *et al.* (dotted line) [16].

ent paper is generally in accordance with the literature data for the proton energy range above 10 MeV, where the η value is close to one. Below 10 MeV, a decreasing trend in η , predicted by a one-hit detector model [9], is not observed. However, considering the uncertainty of η values, the obtained data are in accordance with the data presented by Olsen and Hansen [10], Onori [12] and Bartolotta [1] and with a model prediction presented by Olko [9].

The relative effectiveness of alanine detectors will be a subject of further studies.

Conclusions

The linear relation between the EPR signal of alanine pellets irradiated in modulated 60 MeV proton beam and proton nominal dose values, in the range used in radiotherapy, makes alanine pellets a promising detector for quality control of the therapeutic beams and a good candidate for in-phantom dosimeter.

Alanine films, which also show linear proton dose response, cannot be used in radiotherapy because of their low sensitivity to ionizing radiation. However, they are very useful for the basic research because of the high spatial resolution (0.25 mm).

Relative efficiency of alanine detectors described in this study is close to unity for all the examined proton energies.

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