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An experimental investigation of the electron energy dependence of the EPR alanine dosimetry system

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Abstract

The dose-to-water response of the EPR alanine dosimetry system for various electron beams used in radiotherapy is studied. The EPR alanine dosimetry system is established for high-dose dosimetry, usually transfer dosimetry of ^{60}Co γ-rays. However, for clinical applications, where radiation qualities other than ^{60}Co γ-rays are used, the behavior of the alanine dosimeter response needs to be further investigated. In the present work, electron beams from a clinical linear accelerator of the type Varian Clinac 2100 were used. Alanine dosimeters were irradiated with doses between 16 and 54 Gy in a plastic sleeve at the depths of dose maximum in a water phantom with electron beams of nominal energies of 6, 9, 12, 16 and 20 MeV (corresponding beam quality indices R_{50}: 2.4, 3.4, 4.8, 6.5 and 8.2 cm^2/g). For the electron beams, the dose-to-water was monitored using a plane-parallel ion chamber, while for the ^{60}Co γ-rays, the dose was monitored using a cylindrical chamber that was calibrated with water calorimetry. The obtained alanine dose-to-water responses for electrons relative to ^{60}Co γ-rays indicated a small deviation from unity. An average relative response of about 0.97 for the electron beam qualities is indicated from the data. Possible explanations for the small observed response reduction relative to ^{60}Co γ-rays are discussed.

Keywords: EPR dosimetry; Dosimetry; Alanine; Electron beams; Radiotherapy; Energy dependence; Weighted regression

1. Introduction

The EPR alanine dosimetry system for measuring absorbed doses from ionizing radiation may be valuable for clinical use as a complement to other dosimetry systems, due to various favourable properties: The signal evaluation procedure is non-destructive, the alanine dosimeters are robust, the system has a very wide dose range of constant dose response (for doses below about 5 kGy (Nagy, 2000)), and alanine has a high radical stability and a composition that effectively is fairly similar to that of water. The system has been used for several years for mailed dosimetry of high doses from ^{60}Co γ-irradiation for industrial purposes (Regulla, 2000). Some institutions are applying the EPR alanine dosimetry system for radiotherapy dosimetry intercomparisons (e.g. the ISS, Italy (De Angelis et al., 2002)) while PTB, Germany are currently preparing the replacement of Fricke dosimetry with EPR alanine as a transfer standard.

EPR enables detection of the relative number of free radicals in the alanine dosimeter. To calibrate the readout to absolute dose, the reading as a function of dose-to-*water* is established, usually by measuring the response of dosimeters that have been exposed to ^{60}Co γ-rays with controlled doses-to-water. All doses referred to in the present work, are absorbed doses-to-water when not otherwise

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specified. When applying the EPR/alanine system for radiation qualities different than at calibration, possible energy dependence in the dose response should be accounted for. Recent studies of the alanine dosimeter response for high-energy photons relative to the response of ^{60}Co γ-rays indicate a very small energy dependence, i.e. less than 1% below unity (Bergstrand et al., 2003; Sharpe, 2003; Zeng et al., 2004).

The rather few existing studies of the alanine response for high-energy electron beams, further discussed in Section 3.2, have concluded that there is no statistically significant variation in the dose response for alanine dosimeters with the investigated electron beam qualities. And yet, in some of the few quantitative reports of the measured responses for electrons relative to ^{60}Co γ-rays, a small *reduction* relative to unity was the result (Onori et al., 1990; Sharpe and Burns, 1995).

In the present work, alanine dosimeters were exposed to electrons of nominal energies between 6 and 20 MeV from a common linear accelerator (linac) in use for radiotherapy. For each beam quality, the electron dose response was compared with the dose response for dosimeters of the same production batch that had been irradiated with ^{60}Co γ-rays.

2. Materials and methods

2.1. Alanine dosimeters

The alanine dosimeters (of type Bronze batch 603995/2) were obtained from Bruker GmbH. They have an average mass of 87 mg and are cylindrically shaped, with diameter 4.7 mm and height 4.5 mm. The dosimeters consist of 80% L-α-alanine and 20% polyethylene for binding purposes.

2.2. Irradiation and dosimetry

2.2.1. Irradiation and reference dosimetry for electron beams

The electron beams were delivered by a Varian Clinac 2100 linear accelerator that is in daily use for medical radiotherapy at the Norwegian Radium Hospital. The electron beam qualities were characterized by having nominal energies of 6, 9, 12, 16 and 20 MeV, respectively. The corresponding beam quality indices, R_{50}, and the corresponding depths of dose maximum, z_{max}, are given in Table 2. All electron irradiations were performed in 1 day. The administered doses ranged from 16 to 54 Gy. For each of the electron beams except for 9 MeV, four different dose values were selected, and for each dose value, three dosimeters were irradiated simultaneously. The 9 MeV point had only two dose values of three dosimeters each. The field size at the water surface was 10 cm $\times$ 10 cm and the source–surface distance was 100 cm. The dosimeters were irradiated in a cubic liquid water phantom, side dimension 30 cm, in z_{max}. The dose-to-water (at the effective point of measurement) was monitored during the alanine irradiation with a Roos FK-6 graphite plane-parallel ion chamber. The electron dosimetry was performed in accordance with TRS 381 (IAEA, 1997), before the latest protocol TRS 398 (IAEA, 2001) was put into use.

Before the simultaneous irradiation of the alanine dosimeters and the Roos chamber, the Roos chamber was cross-calibrated against a cylinder chamber type NE2571 that was traceable to the air kerma standard of the BIPM primary standard dosimetry laboratory. The chamber cross-calibration was performed in the 20 MeV beam with a 15 cm $\times$ 15 cm field size.

For all electron beams, a polymethylmethacrylate (PMMA) sleeve with a wall thickness of 1 mm surrounded three stacked alanine dosimeters during irradiation. The combined standard uncertainty in absorbed dose to (unperturbed) water at the effective point of measurement, P_{eff}, as measured with the plane-parallel chamber, was estimated in agreement with TRS 381 (IAEA, 1997) to be about 1.3%. The center of the mid alanine dosimeter and the P_{eff} of the cylindrical chamber held approximately the same position (both transversally and vertically) in the tank for their respective irradiations. Thus, the effects due to a possible non-symmetrical dose distribution in the transversal plane are assumed to be negligible.

2.2.2. ^{60}Co γ-rays and reference dosimetry

One set of alanine dosimeters was exposed with ^{60}Co γ-rays for reference. These dosimeters were irradiated at the National Research Council (NRC) in Canada using their ^{60}Co source situated in an Eldorado 6 (AECL) therapy head. The dosimeters were placed in a PMMA sleeve identical to the one used for the electron irradiations, however this sleeve was inserted into another snugly fitting PMMA sleeve of similar wall thickness in a full-scatter water phantom. Altogether 30 dosimeters were irradiated with 10 different dose points spread between 8 and 51 Gy. The irradiation took place 4 weeks prior to the electron beam irradiations. A minor signal fading is taken into account as further described in Section 2.3. The dose determinations in water for the ^{60}Co γ-rays was based on the NRC calorimetry (Ross and Klassen, 1996). The dose-to-water standard uncertainty is given as 0.4% (Seuntjens et al., 2000).

For the comparison between responses of the electron-irradiated dosimeters which' administered doses were measured by NRPA ion chambers and the γ-irradiated dosimeters which' doses were measured by means of NRC water calorimetry, the dose-to-water evaluated at the NRC was corrected downwards by 1/1.0096 (since relative responses are compared, this is equivalent to shift the dose-to-water based on air kerma calibration upwards by 1.0096). This resultant correction factor is composed of two factors: (1) The difference in absorbed dose-to-water when being based on an absorbed dose-to-water standard relative to being based on an air kerma standard, is accounted for (IAEA, 2001). The respective dose-to-water ratio due solely to the two different kinds of primary standards is estimated to be 1.012 ± 0.003,