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Dosimetry

Realisation of the absorbed dose to water for I-125 interstitial brachytherapy sources

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ABSTRACT

A large air-filled parallel-plate extrapolation chamber in a phantom of water-equivalent material is used as a primary standard measuring device for low-energy interstitial brachytherapy sources from which the unit of absorbed dose to water can be derived. The chamber is suitable for low-energy photons with energies up to 50 keV. The method to determine the absorbed dose to water was newly developed based on radiation transport theory. It offers a clear analytical expression to determine D_w. A conversion factor $C(x_i,x_{i+1})$ has to be applied to the difference of ionization charges measured at two plate separations x_i and x_{i+1}.

The details of the method are presented. The determination of D_w of an I-125 seed is demonstrated by the measurement of a 'BEBIG Symmetra I25.S16' – seed. Additional measurements of the reference air kerma rate with the PTB primary standard chamber GROVEX I allow to determine experimentally the dose rate constant of an I-125 seed by means of primary standards for the first time. Good agreement was found between the obtained dose rate constant and the published data.

Within the EURAMET joint research project 'Brachytherapy' three National Metrology Institutes (NMIs) in Europe are developing new primary standards for the absorbed dose to water (D_w) for low dose rate (LDR) brachytherapy which will replace the current reference air kerma rate (RAKR) standards in the future. The aim is to improve the accuracy and effectiveness of the dosimetry of brachytherapy to a level comparable to that of radiotherapy with external beams.

The German national metrology institute (PTB) decided to base its primary standard on an extrapolation chamber (EXPO) in a phantom of water equivalent material, as, due to its higher sensitivity, ionometric methods seem to be the preferred choice. As existing methods to determine D_w from extrapolation chamber measurements turned out to be not adequate a method was newly developed based on radiation transport theory [1].

The new method offers a clear analytical expression to determine D_w. A conversion factor $C(x_i,x_{i+1})$ has to be applied to the difference of charges measured at two plate separations x_i and x_{i+1}. This factor is composed of quotients of kerma values calculated for different plate separations in the chamber. It has been shown in a recent publication [2] that this conversion factor is robust against uncertainties of database and spectra that is not the case for the conversion factors needed to convert the RAKR into D_w. For photons with energies of about 10 keV the uncertainties of the conversion factors could be reduced from 10% (RAKR) to 1% (EXPO).

In this publication the method of evaluation will be described briefly: theoretical background, experimental set-up, spectrometry and Monte-Carlo (MC)-calculations. The determination of D_w of an I-125 seed is demonstrated by the measurement of a 'BEBIG Symmetra I25.S16' – seed and the uncertainty budget is discussed. Additionally the RAKR is determined with the primary standard GROVEX I [3]. The ratio of both values forms the dose rate constant measured by means of primary standards for the first time. This step allows comparison of the measured results with data from literature.

However, no data are published for the 'BEBIG Symmetra I25.S16' – seed, yet, but data for the BEBIG Symmetra I25.S06' – seeds, which have the same design but a lower concentration of silver iodide in its active core. Evidence is given by MC-calculations that the higher concentration of silver iodide results only in a small, almost negligible variation of the dose rate constant. Therefore, the measured data of the S16 seed can be compared of the published data of the S06 seed.

Theoretical background

The principals of the method of evaluation were developed based on radiation transport theory and are described in detail in [1,2]. Therefore, in this article only a brief summarize is given. The method is based on a Monte Carlo-determined conversion

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factor $C(x_i,x_{i+1})$ to be applied to the difference of the ionization charge for the two plate separations x_i and x_{i+1}. The design of the experimental set-up allows to neglect the contribution due to the net energy fluence of the secondary electrons at the surface of the measuring volume as discussed in [2].

Additional terms must be considered to determine the absorbed dose to water at a point in 1 cm distance from the source in the water phantom. The equation of determination is:

$$D_w = \frac{W}{e}\frac{1}{\rho}\frac{1}{r^2}k_{inv}k_{div}C(x_{i+1},x_i)(Q(x_{i+1})) - Q(x_i))\Pi_i k_i, \quad (1)$$

with the ionization constant (W/e), ρ the density of air, r the source to measurement point distance, k_{div} the conversion from D_w in the measuring area to D_w in a point on the beam axis, $Q(x_{i+1})$ and $Q(x_i)$ the ionization charges measured at the two plate separations x_{i+1} and x_i, which must be greater than the range of the secondary electrons and k_{inv} the correction for deviations from the inverse square law of the distance.

The conversion factor $C(x_i,x_{i+1})$ is given as

$$C(x_{i+1},x_i) = \frac{1}{A}\frac{1}{x_{i+1}\cdot k(x_{i+1}) - x_i \cdot k(x_i)}, \quad (2)$$

with A the area of the measuring volume lateral to the beam axis and $k(x) = \overline{K_a^{ph}(V_x)}/K_w^{ph}(0)$, the ratio between the mean air kerma in the water phantom at plate separation x and the water kerma at zero plate separation. Almost negligible corrections as correction for saturation effect k_{sat} and source-holder scatter correction k_{hold} are subsumed under k_i.

Material and methods

Experimental set-up

The design of the chamber follows the design of PTB's large-volume extrapolation chamber (GROVEX I), with two exceptions: First, the entrance and the back plate (60 mm in thickness) are made of a water-equivalent material (RW1) [4] with a measured density of 0.976 g/cm^3. Thereby, the thickness of the entrance plate (10.49 mm) defines the measurement depth within the water phantom (10.24 mm). Secondly, the cross section of the measuring volume is defined by means of an aperture and not through the size of the measuring electrode.

Fig. 1 illustrates the principles of the GROVEX II measurement system. The source is mounted within a small RW1 cylinder of 0.2 mm wall thickness on the tip of a thin PMMA rod that is rotated at about 0.2 Hz during the measurement to average over any non-uniformities in the radiation field perpendicular to the source axis. A 5 mm thick lead shutter is inserted to allow background and leakage measurements with the source in place.

The front wall of the GROVEX II consists of a lead aluminium sandwich structure with a hole of 27 mm diameter to exclude stray radiation from the measurement. Within the first section of the chamber in 15.77 cm distance from the source an aperture with a radius of 1.515 cm is mounted which defines the cross section of the measuring volume in the reference plane. Graphite was sprayed onto the inner side of the entrance plate. Biased at the potential U, this layer acts as the polarising electrode and serves as the reference plane for the measurement. In front of the back plate, a graphitized polyethylene foil is located. With this foil a centre collecting electrode and an outer guard ring – both at ground potential – are built. The diameter of the collecting electrode amounts to 140 mm.

Spectrometry

The spectra were measured with a HPGe-Detector (Canberra GL0110P) and the relative intensity of the discrete X-ray lines were analysed with Canberra's Genie-2000 software. The detector's efficiency was calibrated by means of activity standards [5]. Several seeds of different batches were analysed to estimate the impact of the variation of the spectra to the final result.

Monte-Carlo calculations

k(x)

The MC-calculations to determine $k(x)$ were performed with EGSnrc [6] using the EGSnrc MC-code in the version V4-2-3-0 in combination with the FLURZnrc user code [7]. The details of the calculation are described in [2]. The calculations were performed for the three databases available in the code (PEGS, NIST and EPDL) to estimate the impact of the uncertainty of the database to the determined quantity.

Conversion from D_w in the measuring area to D_w in a point on the beam axis, k_{div}

The conversion of D_w in the measuring area to D_w in a point on the axis is performed by several MC-calculations (FLURZnrc) with decreasing radii r of the measuring volume. A model-function is fitted to the results to determine D_w ($r = 0$) for a vanishing small

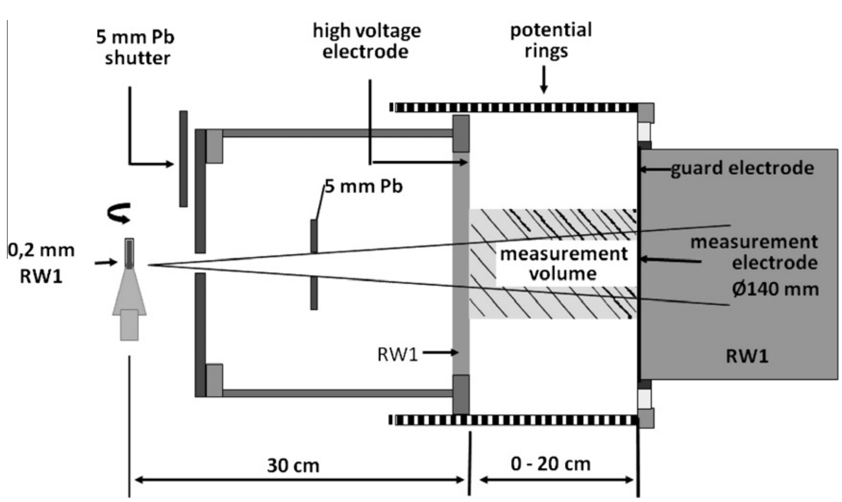

Fig. 1. Principles of the GROVEX II measuring system.