THE MEASUREMENT OF THE CENTRAL-AXIS DEPTH-DOSE CURVE OF BETATRON ELECTRON BEAM IN THE PHANTOM

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Introduction
Up-to-date modern advances in the commercial development of linear accelerators with suitable energy and retractable x-ray targets as well as the development of new radiotherapy methods allow extensive use of electrons for radiation therapy. Thus, it is necessary to have a clear perception of scientific understanding and the methodology of clinical dosimetry of electron beams.

The research objectives are to measure the depth dose distribution of the 2 MeV electron beams of the betatron using plane-parallel ionization chamber and radiochromic dosimetry films (the GafChromic EBT3 films) in non-water phantom and to compare the results obtained.

Materials and methods

Source of emission
The irradiation was performed using the betatron prototype of a new generation. This device allows smooth changing of energy in a wide range depending on clinical applications. The maximum kinetic energy of the electron is 3.5 MeV.

Dosimetry equipment

Plane-parallel ionization chamber
Plane-parallel ionization chambers are acceptable for relative dosimetry of electron beams. In the experiment the standard dosimeter AT5350/1 (date of gauging - 27.09.12) completed with a PTW-Freiburg Markus 23343 parallel-plate chamber (with the dose range 2 – 45 MeV; measuring volume - 0.055 cm²; wall material - polyethylene) was used [1].

Radiochromic films
Radiochromic films are one of the most practical detectors used in non-water phantoms to obtain relative and absolute measurements for clinical electron fields. [2]

The GafChromic EBT3 radiochromic dosimetry film is a new model of sensitive radiochromic films. This film has a series of advantages compared to the older versions of radiochromic films. The GafChromic EBT3 film is made by laminating an active layer between two polyester layers (near the tissue-equivalent). The polyester surface allows water immersion (usable with water phantoms). The GafChromic EBT3 film has a special polyester substrate that prevents the formation of Newton’s Rings interference patterns in images acquired after using flattened scanners. The GafChromic EBT3 film has a symmetrical structure (easy to use) and a wide dose range (1 cGy to > 40 Gy) [3].

Non-water phantom
To carry out some dosimetry measurements in a water phantom it is necessary to use waterproof sheath for the detectors. It is also difficult to make measurements near the surface of the water because of surface tension effects and the finite size of the detector [4]. Also because of the complexity of the water phantom design and preliminary measurement works, the dosimetry process is time consuming. In this case it, becomes necessary to use a solid phantom.

In this work RW3 Slap Phantom T29672 was used. The material of the phantom is polystyrene (C₈H₁₈) containing 2% (±0.4 %) of TiO₂ by mass. The density of the phantom is 1.045 g/cm³. The electron density of the phantom is 1.012 times higher then the electron density of water [5].

Conversion of dose
Provided secondary electron equilibrium exists (normally within a few millimeters of the surface) and the energy spectra at each position are identical, the dose in water at a depth \(d_{\text{water}}\) and the dose in the solid at a corresponding depth \(d_{\text{med}}\) are related by

\[
D_{\text{water}}(d_{\text{water}}) = D_{\text{med}}(d_{\text{med}}) \left[ \frac{\rho_{\text{water}}}{\rho_{\text{med}}} \right] \left[ \frac{S}{\rho_{\text{coll}}} \right]_{\text{med}}
\]

where \(\left[ \frac{S}{\rho_{\text{coll}}} \right]_{\text{med}}\) is the ratio of the mean unrestricted mass collision stopping power in water to that in the solid. \(\rho_{\text{water}}/\rho_{\text{med}}\) is the fluence factor, that is, the ratio of the electron fluence in water to that in the solid phantom. In the first approximation the fluence factor could be equal to 1. The equation (2) is assumed to hold for depths where the mean energies are identical, which are defined to be at equivalent depths for the corresponding depths where the energy spectra are identical.

Water-equivalent depth
The depth in the non-water phantom can be converted to water-equivalent. The water-equivalent depth can be approximated using a density determined from the ratio of the depth of 50% ionization \(R_{50}\) penetrations by

\[
d_{\text{water}} = d_{\text{med}} \times \rho_{\text{eff}} = d_{\text{med}} \left( \frac{R_{\text{water}}}{R_{\text{med}}} \right),
\]

i.e., the effective density, \(\rho_{\text{eff}}\) given by the ratio of the \(R_{50}\) in water to that in the non-water material. The recommended effective density of scaling depth from non-water polystyrene phantoms to water phantoms for electron beams is 0.975.

Materials and methods

Materials
The equipment used in the experiment included a GafChromic EBT3 radiochromic dosimetry film (the GafChromic EBT3 films), a PTW-Freiburg Markus 23343 parallel-plate chamber (with the dose range 2 – 45 MeV; measuring volume - 0.055 cm²; wall material - polyethylene), and a PTW-Freiburg Markus 23343 parallel-plate chamber (with the dose range 2 – 45 MeV; measuring volume - 0.055 cm²; wall material - polyethylene) was used [1].

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Measurements of the depth dose distribution using plane-parallel ionization chamber in non-water phantom

The condition for the expression (1) is that the detector must be of a minimum weight or made of the same material as the phantom in order to create the secondary electron equilibrium.

In the measurement of the depth dose, the conversion of ionization to the dose is given by

\[ D_{\text{water}}(d_{\text{water}}) = N_{\text{gas}} Q_{\text{corr}}(d_{\text{med}}) \left( \frac{[\Phi/L]_{\text{coll}}}{\rho_{\text{med}}} \right) \text{med} P_{\text{repl}} \times \left( \frac{\bar{\sigma}}{\rho_{\text{med}}} \right)_{\text{water}} \left( \frac{\bar{\sigma}}{\rho_{\text{med}}} \right)_{\text{water}}, \]

where \( N_{\text{gas}} \) is the cavity-gas calibration factor; \( Q_{\text{corr}}(d_{\text{med}}) \) is the corrected ionization reading; \( \left( \frac{[\Phi/L]_{\text{coll}}}{\rho_{\text{med}}} \right) \text{med} \) is the ratio of the mean restricted mass collision stopping power in the solid to that in air; \( P_{\text{repl}} \) is the chamber replacement factor, it is equal to 1 for plane-parallel ionization chambers. The percent depth dose is then given by

\[ \%D_{\text{water}}(d_{\text{water}}) = \left[ \frac{Q_{\text{corr}}(d_{\text{med}}) \left( \frac{[\Phi/L]_{\text{coll}}}{\rho_{\text{med}}} \right)_{\text{water}}}{[\Phi/L]_{\text{coll}}}_{\text{max}} \right] \times 100, \]

where the denominator equals the value of the numerator at the depth-of-the-maximum dose; \( \left( \frac{[\Phi/L]_{\text{coll}}}{\rho_{\text{med}}} \right)_{\text{water}} \) is the ratio of the mean unrestricted mass collision stopping power in water to that in the air [4].

Measurements of the depth dose distribution using GafChromic EBT3 radiochromic dosimetry films in non-water phantom

Measurement of the central-axis depth-dose curve can be done with a film placed between the plates of solid phantom parallel to the electron beam [2].

The dose that films have received can be correlated to their change in optical density. The digital images of the film are a data set consisting of the values of color intensity. The fitted calibration curve allows calculating the value of the absorbed dose received from the given source of radiation in accordance with the value of the relative optical density [6].

In this case, considering the equation (1), the percent depth dose in water can be given by

\[ \%D_{\text{water}}(d_{\text{water}}) = \left[ \frac{D_{\text{med}}(d_{\text{med}}) \left( \frac{\bar{\sigma}}{\rho_{\text{med}}} \right)_{\text{water}}}{[\Phi/L]_{\text{coll}}}_{\text{max}} \right] \times 100 \]

where the denominator equals the value of the numerator at the depth-of-maximum dose. [4]

Results and discussion

In figure 1 the results of the depth dose measurement of the 2 MeV electron beams of the betatron using the plane-parallel ionization chamber and the GafChromic EBT3 films in the phantom are shown.

**Fig. 1.** Comparison of the film dosimetry results with the ionization chamber results (2 MeV electron beams of the betatron):
- the depth dose distribution using plane-parallel ionization chamber in the non-water phantom;
- the depth dose distribution using plane-parallel ionization chamber in water;
- the depth dose distribution using the GafChromic EBT3 radiochromic dosimetry films in water.

**Conclusion**

The measurements performed on the 2 MeV electron beams of the betatron show that the qualitative results obtained with the help of the GafChromic EBT3 films and the plane-parallel ionization chamber are in good agreement.

However, the values of the absorbed dose to the depth dose curves on the central axis quantitatively differ in the beginning of recession. This is explained by the fact that the betatron is being under development, consequently, the betatron did not work continuously and the measurements were carried out in different days.

**References**

1. User manual Markus chamber Type 23345 D273.131.00/07 2006-07 Hn
5. Instruction manual RW3 Slab Phantom T29672 and T40006.1.001 D188.131.00/04 2007-07 Chr/Si/Sa