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Determination of Effective Spectrum of Medical Linear Electron Accelerators from Depth Dose Distributions

Zh. Galyautdinova, V.A. Klimanov, and M.A. Kolyvanova

State Research Center - Burnasyan Federal Medical Biophysical Center of Federal Medical Biological Agency, Moscow, Russia

Abstract

Development of the spectrum reconstruction method for bremsstrahlung beams with different field sizes, created medical electron linear accelerators (LAE), on the base of the deep dose distributions in a water phantom and determination of photon spectra for Varian Trilogy accelerator 6 MV.

The proposed methodology is based on the use of dose kernels algorithm of point monoenergetic monodirectional source (pencil beam (PB)) for the depth dose distribution calculation, created different cross-section beams of in a water phantom, and experimental measurements of these distributions. For solving the inverse problem is applied Toolbox routines 'Optimtool' knowing mathematical package MATLAB to solve.

Bremsstrahlung energy spectrum generated medical accelerator Varian Triology with different sizes of square fields from 3 x 3 up to 40 x 40 cm2 and average energy photons, depending on the size of the fields were received. Dose kernels for a set of defined energies PB were calculated. Depth dose distribution in a water phantom, calculated using the obtained spectra and dose kernels agree well with measurement dose distributions.

The proposed technique reconstruction of bremsstrahlung spectrum of medical accelerator is good adequate. Average energy spectra of photons for Varian Trilogy Accelerator in regime 6 MV varies from 1.71 to 1.43 MeV depending on the field size.

Keywords: radiation therapy, medical accelerators, bremsstrahlung, reconstruction of the photon spectrum.

Corresponding Author:
Zhanneta Galyautdinova
Janneta1984@mail.ru

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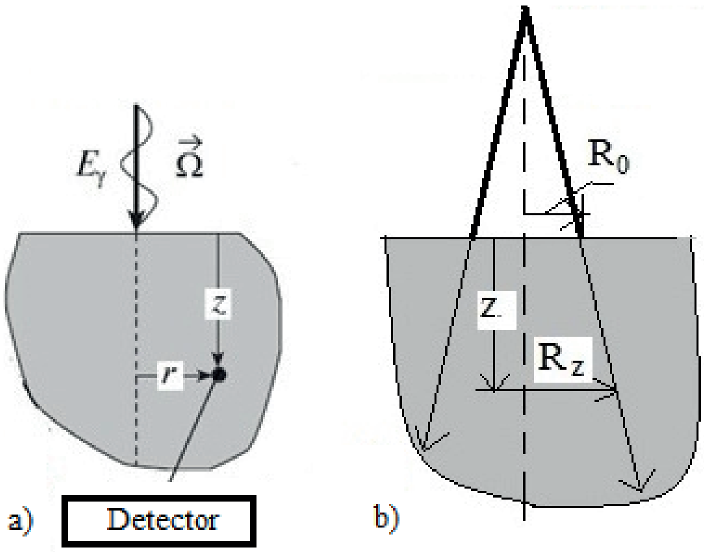
1. Introduction

As a rule, at a depth of 10 cm in a water phantom, smoothing filters are placed on the path of the beams. They have a complex cone-shaped shape, which leads to an increase in the absorption of low energy photons with a decrease in the angle between the direction of their trajectory and the geometric axis of the beam. As a result, the photon spectrum becomes dependent on the field size.

2. Spectrum reconstruction

2.1. Pencil beam kernel method

The dose kernel is defined as the relative fraction of the photon energy PB that normally falls on a semi-infinite water environment at a point that is absorbed per unit volume of the environment near the calculation point $\vec{r}$. The PB dose kernel depends on the position of the point $\vec{r}$ relative to the point $\vec{r}'$ and on the initial photon energy E_0. We denote it by $K(E_0, \vec{r}' - \vec{r}')$. When using a cylindrical coordinate system with the origin at the point of incidence of a pencil beam (Fig. 1, a), the dose kernel becomes a function of the depth of the calculation point z and the distance r from the PB axis – $K\left(E_0, z, r\right)$.



(a) Pencil beam (b) Conical beam

Figure 1: There are two figures illustrated beam geometry.

Assuming the spatial invariance of the PB dose kernel, the dose value created in the water phantom at the depth z on the axis of the conical beam of photons diverging from the point of the Linac target (Fig. 1, b) can be determined from (1):

$$\begin{aligned} D(z) &= \frac{2\pi \cdot \Phi_0}{(1 + z/F)^2} \int_0^{E_{\max}} f(E) \cdot dE \int_0^{R_z} r \cdot K(E, z, r) \cdot dr \\ &= \frac{\Phi_0}{(1 + z/F)^2} \int_0^{E_{\max}} f(E) \cdot dE \cdot K_{int}(E, z, R_z) \cdot dE \end{aligned} \quad (1)$$

where Φ_0 – fluence of photon energy on the surface of a water phantom within the circular cross-section of the radiation field under the assumption of a uniform distribution of the fluence along the radius r, $f(E)$ – the spectrum of the incident photon beam by energy; E_{max} – the maximum energy of photons in the spectrum; F – the distance from the target to the surface of the phantom; R_z – field radius at depth z, equal to $R_z = R_0 \cdot (1 + z/F)$; R_0 – the radius of the field on the surface of the phantom; $K_{int}(E, z, R)$ – according to the terminology proposed in [1], the integral form of the PB dose kernel of photons with energy E, equal to (2):

$$K_{int}(E, z, R) = 2\pi \int_0^R r \cdot K(E, z, r) \cdot dr \qquad (2)$$

If now there are experimental data on the distribution of the absorbed dose along the beam axis at different depths z_i in the water phantom and the values of the integrated dose kernel at the same points are known for a sufficiently detailed set of energies E_j, then (1) can be rewritten in a discrete form:

$$D(z_i) \cong \frac{\Phi_0}{\left(1 + z_i/F\right)} \sum_{j=1}^{N} f(E_j) \cdot K_{int}(E_j, z_i, R_{z_i}) \cdot \Delta E \qquad (3)$$

where N – number of energies for which integral dose kernel are known; $f\left(E_j\right)$ – the number of photons in the spectrum of the incident beam in the interval ΔE.

2.2. Photon transport modeling

Their solution is usually carried out using iterative algorithms and initial approximation to the sought spectrum. The final uncertainty strongly depends on the conditionality of the matrix of the integral dose kernel and the successful choice of the initial approximation to the spectrum.

The dose distributions in water for the PB geometry were calculated by the Monte Carlo method under the EGSnrc program [2], which is an improved version of the EGS4 code

In the work, the calculation was carried out for the collection of energies of monoenergetic PB in the range from 0.25 to 5.75 MV with an increment of 0.5 MV with a 2% energy loss at the enlarged step of the charged particles until a statistical error of ~1% was reached.

2.3. Iterative algorithms

The solution (3) with respect to the photon spectrum was carried out in two stages. At the first stage, the nonlinear regression method implemented in the *lsqcurvefit* subroutine of the mathematical package MATLAB 7 was used. This subroutine performed iterative selection of the spectral values in separate energy groups, minimizing the standard deviation of the resulting calculated dose distribution (in accordance with (3)) from the experimental data for a particular the field size. For the initial approximation to the spectrum, the 6-MV bremsstrahlung photon spectrum of the Varian Trilogy accelerator, incident on a phantom within a circle with a radius that was calculated in [3] by the Monte Carlo method in the BEAM program, was chosen [4].

At the second stage, the genetic optimization toolbox of the mathematical package MATLAB 7 was used for a more accurate selection of the spectrum. In this subroutine, the minimum of the objective function is sought using random search controlled by a genetic algorithm. For the objective function in this case, the sum of the squared deviations of the calculated values of the axial dose distribution from the measured dose values was taken. The spectral values obtained in the first stage were used for the initial approximation.

3. Results

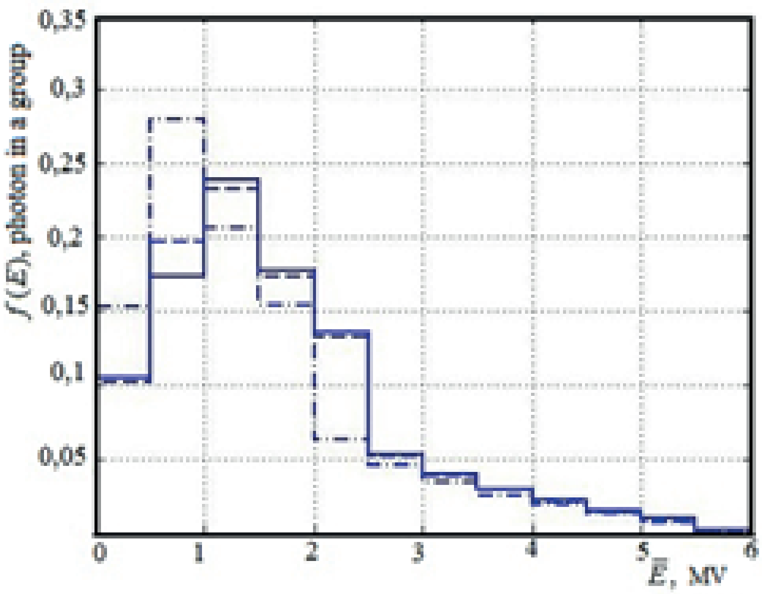


Figure 2: There is figure illustrated Energy effective spectra of bremsstrahlung photons on the surface of a water phantom averaged within three round fields equivalent in square fields to 6 MV Clinac Trilogy. Legend:– - 4 x 4 the field size; – – – - 10 x 10; –·–– - 40 x 40cm^2.

The data presented demonstrate an increase in the contribution of the low-energy part of the spectrum with increasing field size. This effect is even more clearly illustrated in Fig. 3.

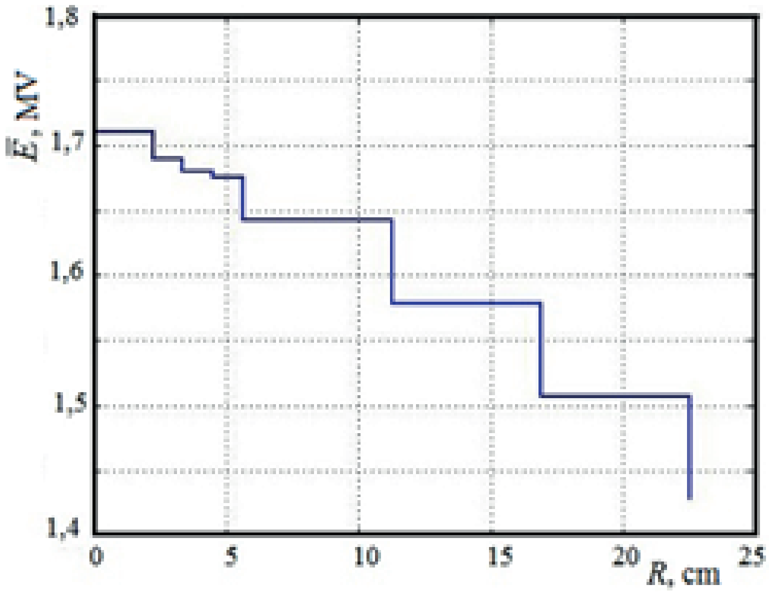


Figure 3: Dependence of the average energy of the bremsstrahlung photons incident on the surface of the water phantom within the round fields equivalent in area to the cross sections of the corresponding square fields, from the radii of the round fields for the 6 MV Varian Trilogy Linac.

The difference in the calculated values from the experimental data for depths exceeding the area of build up for all field sizes, except for 30x30 and 40x40 cm^2, did not exceed 2.0%. For large fields, the difference in dose reached 3.5% at. In this case, the cause of the larger discrepancy is apparently not the allowance for the oblique incidence of a part of the beam photons.

4. Conclusions

A relatively simple and reliable method for reconstructing the bremsstrahlung spectra of medical linear accelerators according to the depth dose distributions in a water phantom is proposed.

The method is based on a preliminary calculation of the dose kernels of monoenergetic PB in water in the energy range corresponding to the reconstructed spectrum.

To obtain the values of dose kernels, it is possible to use the freely distributed EGSnrc code, in order to solve the inverse problem of spectrum reconstruction, you can use the Toolbox 'Optimtool' of the mathematical package MATLAB.

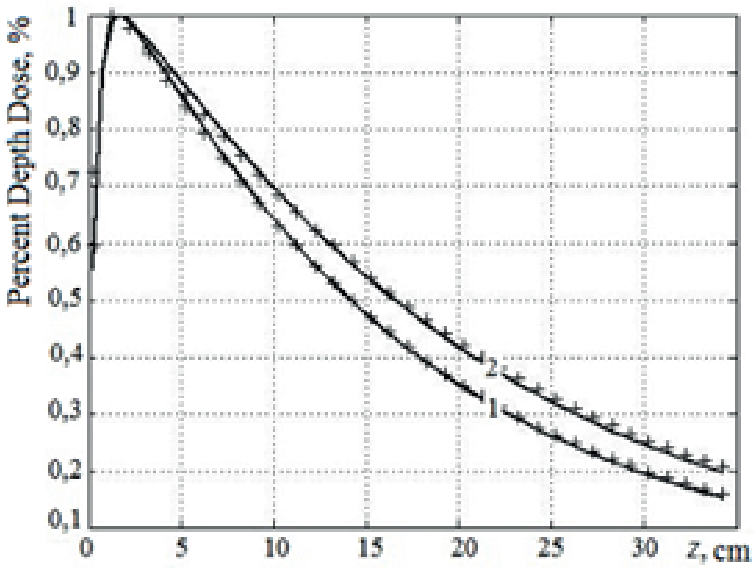


Figure 4: Comparison of the measured (+) and calculated (-) distributions of the percentage dose for the square fields 4x4 (1) and 10x10 cm2 (2) in the water phantom for the corresponding values of the reconstructed bremsstrahlung spectra.

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