PHOTON BEAM MODELLING WITH PINNACLE^3 TREATMENT PLANNING SYSTEM FOR A ROKUS M Co^{60} MACHINE*

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The basic relationships of the convolution/superposition dose calculation technique are reviewed, and a modelling technique that can be used for obtaining a satisfactory beam model for a commercially available convolution/superposition-based treatment planning system is described. A fluency energy spectrum for a Co^{60} treatment machine obtained from a Monte Carlo simulation was used for modelling a fluency spectrum for a Rokus M machine. In order to realize this model we measured the depth dose distribution and the dose profiles with a Wellhofer dosimetry system. The primary fluency was iteratively modelled by comparing the computed depth dose curves and beam profiles with the depth dose curves and crossbeam profiles measured in a water phantom. The objective of beam modelling is to build a model of the primary fluency that is incident on the patient, which can then be used in the calculation of the dose deposited in the patient.

Key words: treatment planning, beam modelling.

INTRODUCTION

In this paper, a basic beam modelling technique that can be used to obtain a satisfactory beam model for the ADAC Pinnacle^3 Treatment Planning System (referred to hereafter as a 3D convolution-based treatment planning system) is described. Photon beam modelling is the process of modelling the distribution of the primary fluency, Φ_0 that is emitted from the Co machine head. The primary fluency is iteratively modelled by comparing the computed depth dose curves and beam profiles with the depth dose curves and cross-beam profiles measured in a water phantom (that is, a forward problem is solved through iteration). The depth dose curves and beam profiles are computed using the convolution model described in the following section.

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PHOTON BEAM MODELLING ON A COMERCIALLY AVAILABLE CONVOLUTION-BASED TREATMENT PLANNING SYSTEM

For the case of a homogeneous medium, the absorbed dose $D(\mathbf{r})$ at the point **r**, from energy released at the point r', can be expressed as [2, 5]:

$$D(r) = \int d^3r' T(r') A(r - r') \tag{1}$$

where the kernel $A(r - r')$ represents the ratio of the energy deposited in a volume d^3r around **r** to the total energy released by photons undergoing radiation interactions in a volume d^3r' around the primary site r'. The (3D) terma distribution is given by:

$$T(r') = \frac{\mu}{\rho} \psi(r') \tag{2}$$

where $\frac{\mu}{\rho}$ is the mass attenuation coefficient and $\psi(r')$ is the energy fluency at depth.

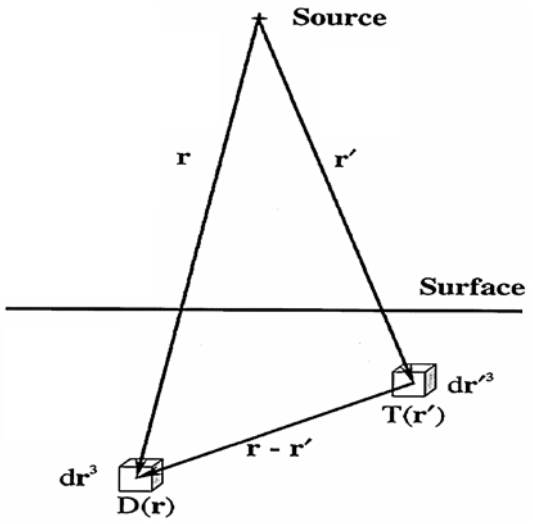

Fig. 1 – Schematical representation of the convolution/superposition equation.

For a parallel monoenergetic photon beam of energy h, which is incident on a flat homogeneous water phantom, the dose at any point **r** within the phantom, is given by:

$$D(r, h\nu) = \frac{\mu}{\rho}(h\nu) \int d^3r' \Psi(r' \cdot h\nu) A(r - r', h\nu) \tag{3}$$

where the primary energy fluency is given by the following expression:

$$\psi(r', h\nu) = \phi(r', h\nu) h\nu \tag{4}$$

where,

$$\Phi(r', h\nu) = \phi_0 \exp\left[-\mu(h\nu) d'\right] \tag{5}$$

In the above expression, ϕ_0 denotes the primary photon fluency emanating from the accelerator head, which is incident on the flat surface of the water phantom, and d' is the distance along r' from the surface of the phantom to the interaction point.

Let us first assume that we have a polyenergetic photon beam consisting of n different monoenergetic photon beams of energy $h\nu_i$, $i \in (1, n)$, each having the energy fluency $\psi(r', h\upsilon_i)$, $i \in (1, n)$; the absorbed dose at the point r is given by the following linear superposition:

$$D(r) = \sum_{i=1}^{n} D(r, h\nu_i) = \sum_{i=1}^{n} \frac{\mu}{\rho}(h\nu_i) \int d^3 r' \Psi(r', h\nu_i) A(r - r', h\nu_i) \tag{6}$$

Hence, for a polyenergetic diverging photon beam that has the fluency spectrum $\psi_{h\upsilon}(r) = d\psi(r, h\nu)/dh\nu$, the dose in a homogeneous medium is given by:

$$D(r) = \int d^3 h\nu \frac{\overline{\mu}}{\rho}(r') \left[\overline{h}\nu\right](r') \overline{F}(r') \Phi_0 \left(\frac{|r_0|}{|r|}\right)^2 \overline{A}(r', r - r') \tag{7}$$

where

$$\frac{\overline{\mu}}{\rho}(r') = \frac{\int dh\nu \left[\mu/\rho\right](h\nu) \Psi_{h\nu}(r')}{\int dh\nu \Psi_{h\nu}(r')} \tag{8}$$

is the average mass attenuation coefficient, and

$$\overline{h}\nu = \frac{\int dh\nu h\nu \left[d\Phi(r', h\nu)/dh\nu\right]}{\int dh\nu \left[d\Phi(r', h\nu)/dh\nu\right]} \tag{9}$$

is the average energy.

$$\overline{F}(r') = \frac{\int dh\nu \exp(-\mu d') \left[d\Phi_0(h\nu)/dh\nu\right]}{\int dh\nu \left[d\Phi_0(h\nu)/dh\nu\right]} \tag{10}$$

is the attenuation in the phantom, and Φ_0 is the total primary fluency incident on the surface of the phantom.

As pointed out in Papanikolaou *et al.* [1], this chain of operations would be very inefficient and time consuming, in terms of CPU time. Therefore, the correction factor was introduced in equation (12) calculated with the help of the incident fluency spectrum.

COMPONENTS METHOD

Alternatively, the absorbed dose $D(\mathbf{r})$ at the point can be calculated from a polyenergetic photon beam from monoenergetic distributions using the component model [5]:

$$D(r) = \int dh\nu \frac{D(r, h\nu)}{\Phi_0} \frac{d\Phi_0}{dh\nu} \tag{11}$$

As pointed out in Papanikolaou *et al.*, the component model correctly deals with spectral hardening. However, it has the disadvantage that separate convolutions must be performed for each spectral bin.

Using either of the above outlined models, one can calculate depth dose curves and crossbeam profiles at given depths as relative dose curves; the former normalized to the dose at Dmax and the latter normalized to the central axis dose at a given depth.

PHOTON BEAM MODELING PROCEDURE ON PINNACLE[3]

For each photon beam to be modelled, the following minimal set of data is required. All data should be acquired using a water phantom.

- Depth dose curves from which the energy spectrum is determined.
- Dose profiles for determination of the incident energy fluency inside the field.
- Dose profiles extending outside the field for determination of scatter dose from the machine head components.
- The calibration output factor.
- The relative output factors.

MODELLING AN OPEN PHOTON BEAM

In order to model a photon beam for the Rokus M. Machine from the „Sf. Spiridon" Hospital, the measurements for the dose profiles and the depth dose were performed with a dosimetric system Wellhofer, and the doses were measured in air, at a distance of 75 cm from the machine head, for all the field sizes (2 × 2 to 24 × 24 cm), with a cylindrical ionisation chamber, with a volume of 0.6 cm^3.

The steps to be followed in the beam modelling process are [3]:

1. The phantom size and fluency grid resolution based on the depth of the measured data and the field size is selected. For all field sizes, one can use a fluency grid resolution of 0.3 cm, a lateral phantom size of 70 cm, and a phantom

depth that exceeds the maximum depth of the percentage depth dose by 10 cm (10.5 cm in our case).

2. The selection of the initial spectrum to be used for your beam. A number of published and interpolated spectra are available in the literature. The software contains a number of published and interpolated spectra for use as the starting point to model your beam. Generally, one should start the modelling process with a spectrum of the same energy as your beam if one is available. If the exact energy is not available, select the spectrum with the nominal energy closest to but greater than your beam's nominal energy.

The user may introduce a spectrum obtain through theoretical or experimental estimation. The spectrum used is obtained experimentally through measurements performed with the ROKUS M installation in our clinic (Fig. 2).

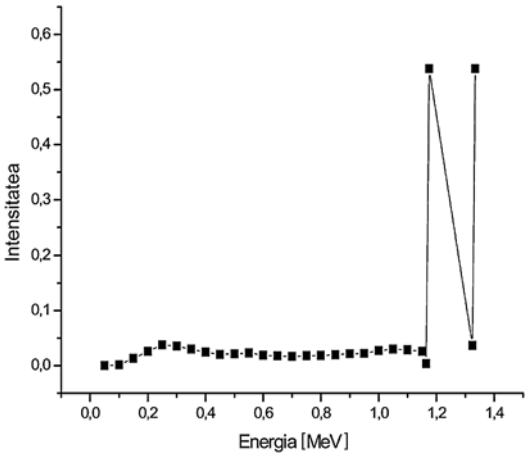

Fig. 2 – The energy spectrum emitted by a source of Co^{60}.

3. The measured and computed depth dose curves are compared and the spectrum is adjusted until the shape of the two curves matches well. One has to compare the measured open field depth doses for the 5 × 5, 10 × 10, 20 × 20 and largest field size (24 × 24 in our case).

4. The coarse adjustment of the parameters as effective source size, Gaussian height and width, jaw transmission factors, until the fit is within 5% in the tails of the profiles and in the high dose region of the profiles.

5. The computation of all profiles and all field sizes and the comparison of the match for all profiles.

6. One must compute the output factors for the beam, then, compute the output factors for a beam of a specific energy, enter the calibration output factor measurement and the relative output factor measurements. The measured collimator scatter factor is commonly called the output factor and may be defined as the ratio of the output in air for a given field to that for a reference field (10 × 10 cm).

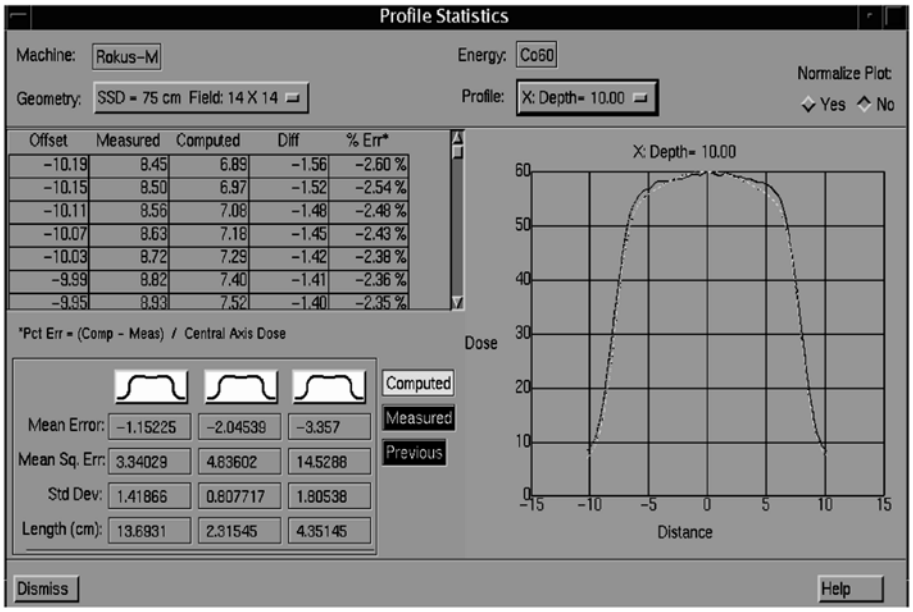

Fig. 3 – The calculation of the profiles for a 14 × 14 field.

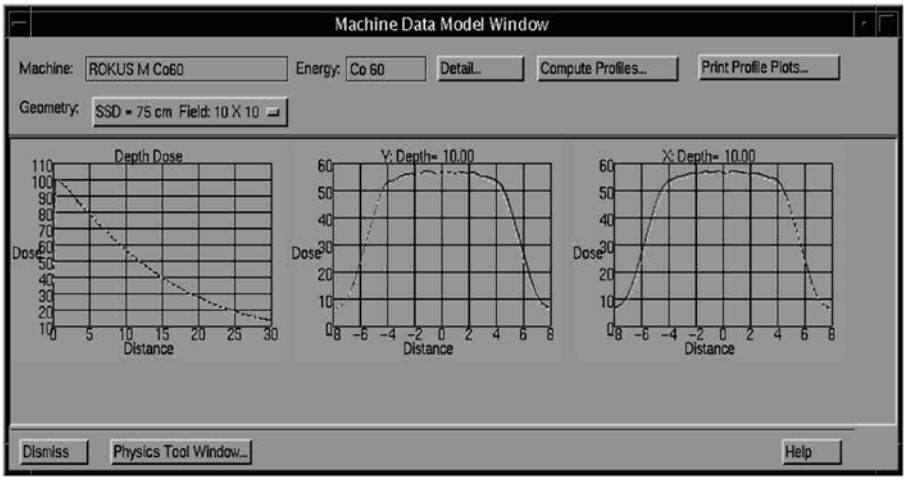

Fig. 4 – The comparison of the profiles and the depth doses for a 10 × 10 field.

Pinnacle computation of the phantom scatter factor (OFp) and the collimator scatter factor (OFc), witch are different from those introduced because they represent the head scatter that is not already included in the photon model. If all head scatter effects have been incorporated into the model, OFc should be 1 for all field sizes. In practice, there may be a slight increase in the computed OFc values with increasing field size.

The phantom scatter factor, for a field with a certain size, is computed with [4]:

$$OF_p = \frac{OF}{OF_C} \tag{12}$$

where OF are the value of the output factor introduce by we.

CONCLUSIONS

The beam modelling procedure described in this paper can be employed successfully to model a photon beam manually. However, it is probably most useful as a guide in what happens when one applies the various automodelling sequences provided in the treatment planning system. It is the modeller's responsibility to ensure that the resulting fluency model is adequate.

One obvious weakness of the current fluency model implemented in the treatment planning system is that the extra focal radiation emanating from the flattening filter is inadequately taken into account by the Gaussian height and width parameters. Most of the time, this precludes the use of a single beam model for all field sizes, and necessitates the use of multiple models for different field sizes. However, it is expected that with the implementation of the dual source model into the fluency model this limitation should be overcome and one will indeed be able to model all field sizes using a single model.

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