DETERMINATION OF ENERGY SPECTRA IN WATER FOR 6 MV X RAYS FROM A MEDICAL LINAC*

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There is a lack of extensive data comprising energy spectra in water for beams generated by medical accelerators applied in radiotherapy. The purpose of this work was the determination of energy spectra in water for the 6 MV X-ray therapeutic beam from the medical linac — Clinac 2300 by Varian. The spectra were derived with the use of Monte Carlo computer simulations basing on MCNPX code in version of 2.7.0. The performed investigations indicate that shapes of the spectra as well as the mean energy of the considered beams depend on a depth in water, a distance from the central-axis of the beam and a radiation field size. The obtained results are valuable for constructors of medical linacs and, additionally, they can be applied in advanced treatment planning systems. Therefore, all obtained spectra in a numerical form are available for common use. They will be sent to users after forwarding e-mail message to the authors of this paper.

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1. Introduction

The purpose of this work was determination of energy spectra in water for the 6 MV X-ray beam generated by the linear medical accelerators — Clinac 2300 applied in many European oncology centers. Energy spectra of therapeutic beams are applied in contemporary treatment planning systems. Moreover, the spectra of therapeutic beam are valuable for constructors of medical linacs. However, there is a lack of extensive data comprising the energy spectra in water — the medium recommended by dosimetry protocols for dosimetry calculations and measurements. The Monte Carlo computer simulation is considered to be the most accurate method to derive these spectra. The experimental methods are mainly used to obtain the spectra

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in air [1–3]. The main requirement to get realistic results with the use of the Monte Carlo method is an agreement between the dose distributions from simulation and from experiment. In the specialist literature, one can find many tests of various Monte Carlo codes as BEAM [4], MCNP4C [5], Geant3 [5], Geant4 [6–9] *etc.* In the presented investigations, the commercial Monte Carlo MCNPX software in version of 2.7.0 was applied. The simulations were performed using the computer cluster at the Department of Nuclear Physics and Its Applications in the Institute of Physics of University of Silesia in Katowice (Poland). The data verifying the simulations were measured by means of the 6 MV X-ray beam from the Clinac 2300 linear accelerators installed in the Centre of Oncology in Gliwice (Poland). This work is a continuation of the investigation presented in [9].

2. Materials and methods

2.1. Method

This work can be divided into two stages. At the first stage, the simulations were verified. The verification was performed by a comparison between the calculated and measured relative central-axis dose curves and relative dose profiles in water for chosen irradiation conditions *i.e.* for the radiation field sizes of 3 cm × 3 cm, 10 cm × 10 cm, 40 cm × 40 cm and for SSD = 100 cm. The regions with the most dose gradient (*i.e.* with the smallest accuracy of measurements of a dose) were excluded from the comparison to obtain the reliable verification. The good agreement between calculated and measured dose distributions in water is a fundamental requirement to derive the realistic spectra. At the second stage of the work, the energy spectra of the 6 MV X-ray beam were calculated using the verified simulations.

2.2. Simulations

All linac head components affecting quality of radiation were taken into account in the simulation program *i.e.* the copper target, the copper flattening filter, the tungsten primary collimator and the tungsten jaws. The simulation setup was based on the data given by the manufacturer. The simulated objects were reconstructed with a very high precision *i.e.* all lengths and thicknesses could differ less than 0.1 mm from the real ones whereas all angles could differ less than one agree. The simulations started from hits of the 6 MeV electrons in the target. The verification of energy spread, geometrical properties of electron beam source *etc.* was performed in our previous work presented in [9].

2.3. Measurements

The measurements of the relative dose distributions in water were carried out using a standard Markus type ionization chamber PTW 23343 recommended by dosimetry protocols (for example, [10]) for that type of dosimetry and an automatic water phantom set making it possible to get the very good reproducibility of an ionization chamber positioning (0.1 mm). The measured central-axis dose curves and profiles taken for the comparison were an averaged data from series of measurements for the group of accelerators.

3. Results and discussion

The measured and calculated dose distributions were specially prepared for the accurate comparison. The central-axis dose curves were normalized to the maximum dose whereas the profiles were normalized to the dose at the central-axis of the beam. Moreover, the curves from simulations were corrected for statistical fluctuations. In the case of the relative central-axis dose curves, an $ax^b \sin(cx^d)$ function was fitted to the points from the simulation whereas the ax^2+bx+c polynomial was the fitted function for the profiles. The comparison of the relative central-axis dose curves in water for the chosen irradiation conditions is presented in Fig. 1 (a). The estimated local dose differences do not exceed 4% and they are mostly less than 2% for the considered relative central-axis dose curves. The average value of the local dose differences is equal to 0.8%. The comparison of the relative dose profiles for the chosen radiation field of 40 cm × 40 cm is shown in Fig. 1 (b). In the case of the profiles, the estimated local dose differences do not exceed 2.5% whereas their average value is 0.9%. The exemplary energy

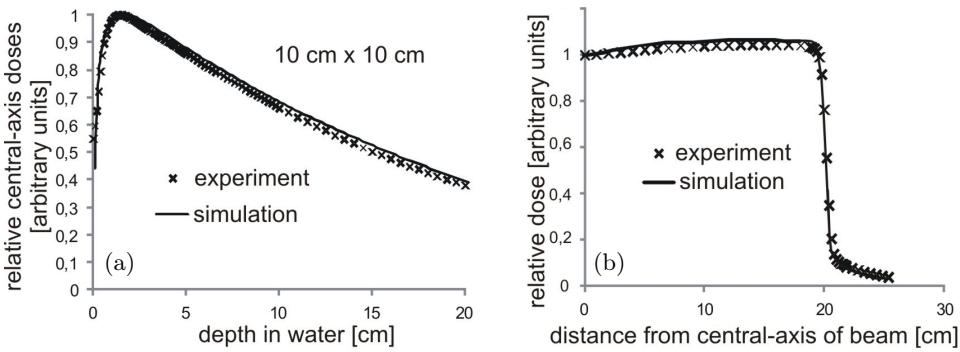

Fig. 1. (a) The comparison between the relative central-axis dose curves in water for the radiation field of 10 cm × 10 cm and SSD = 100 cm. (b) The comparison between the measured and calculated relative dose profiles for the radiation field of 40 cm × 40 cm and SSD = 100 cm.

spectra along the central-axis of the beam are shown in Fig. 2 (a) and (b) whereas those determined in the plane perpendicular to the beam central-axis are illustrated in Fig. 2 (c) and (d). Change of the mean energy of the

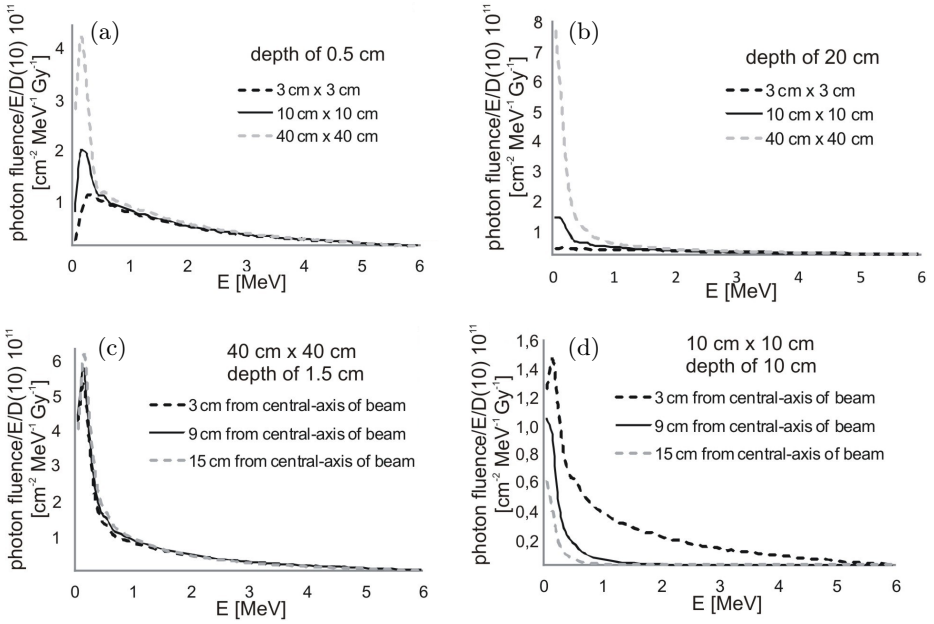

Fig. 2. The energy spectra of the 6 MV X-ray beam from the Clinac 2300. The spectra were determined along the central-axis of the beam in water for radiation fields of 3 cm × 3 cm, 10 cm × 10 cm and 40 cm × 40 cm (SSD = 100 cm) (a) at the depth of 0.5 cm and (b) at the depth of 20 cm. The spectra in water at different distances from the central-axis of the beam (c) for the radiation field of 40 cm × 40 cm at the depth of 1.5 cm and (d) for the radiation field of 10 cm × 10 cm at the depth of 10 cm (SSD = 100 cm).

beam along the beam central-axis is presented in Fig 3 (a). The dependence between the beam mean energy and the distance from the central-axis of the beam at the chosen depth in water is shown in Fig. 3 (b). The spectra and the mean energy of the beam depend on the depth in water and on the radiation field size as well as on the distance from the central-axis of the beam. In the case of the 3 cm × 3 cm radiation field, the mean energy of the beam increases with the increasing depth in water along the central-axis of the beam contrary to that for the radiation fields of 10 cm × 10 cm and 40 cm ×40 cm. The mean energy ranges from 1.67 MeV (on the surface of water) to 1.86 MeV (at the depth of 20 cm) for the 3 cm × 3 cm field whereas it is between 1.27 MeV (at 20 cm) and 1.47 MeV (on the water surface) for the field of 10 cm × 10 cm. In the case of the largest considered

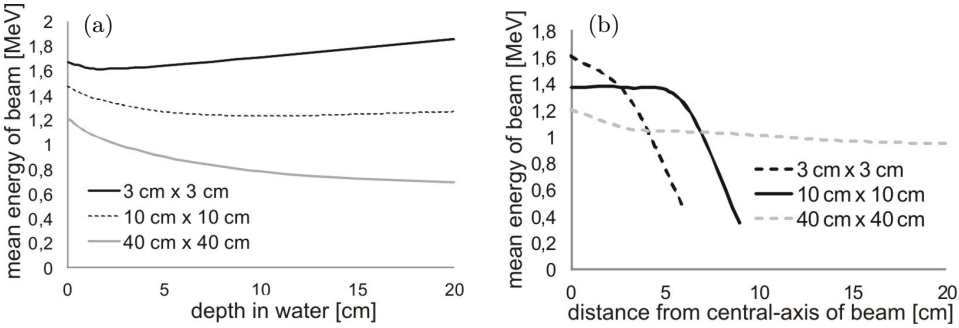

Fig. 3. The mean energy of the 6 MV X-ray beam from the Clinac 2300 (a) *versus* the depth along the beam central-axis in water and (b) *versus* the distance from the central-axis of the beam at the depth of 1.5 cm, for various radiation fields and SSD = 100 cm.

radiation field, the beam mean energy decreases with the increasing depth from 1.21 MeV (on the water surface) to 694 keV (at 20 cm). The mean energy of the beam depends strongly on the contribution from the lower-energy gammas scattered in water. This contribution significantly increases for larger radiation fields. The changes of the spectra are less in the planes perpendicular to the central-axis of the beam, of course, except for regions within the profiles edges. All relative dose distributions as well as all spectra were obtained for 9×10^8 primary electrons.

4. Conclusions

The performed verification of the simulations indicates that the used version of the MCNPX code is suitable for the application in the clinical dosimetry.

The statistical fluctuations can be successfully reduced not only using the appropriate fit but also increasing a number of primary electrons for each simulation. However, the increase in a number of primary electrons needs an increased computer power, otherwise the time of simulations is getting longer.

The spectra were obtained for the geometry and the materials of the Clinac 2300 linac head. The obtained spectra can also be representative for 6 MV X-ray beams from all family of the Clinac models utilizing the same beam-line components *i.e.* Clinac 2100, 1800, 21EX and 23EX. However, the comparison of the dose distributions in water has to be carried out before the spectra will be adopted for another model of Clinac. The good agreement between these dose distributions is a necessary condition.

All spectra in a numerical form are available for common use, because of their practical values. The spectra will be sent to users after forwarding e-mail message to the authors of this paper.

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