Numerical Simulation of the Medical Linear Accelerator Electron Beams Absorption by ABS-Plastic doped with Metal

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Abstract. In this paper the numerical simulation results of the dose spatial distribution of the medical electron beams in ABS-plastic doped with different concentrations of lead and zinc are shown. The dependences of the test material density on the lead and zinc mass concentrations are illustrated. The depth dose distributions of the medical electron beams in the modified ABS-plastic for three energies 6 MeV, 12 MeV and 20 MeV are tested. The electron beam shapes in the transverse plane in ABS-plastic doped with different concentrations of lead and zinc are presented.

1. Introduction

Radiation therapy uses a wide range of radiation for neoplasms treatment: gamma rays, X-rays, protons, neutrons and electrons [1–8]. Nowadays, one of the most interesting directions of the electron beam medical application is an intraoperative therapy [3]. For these purposes it is necessary to have the possibility of beam profile modulation. For example, new methods of the collimators and filters production allow to increase the accuracy of dose delivery to the target.

The intraoperative therapy procedure requires careful planning for the determination of the geometry and operating modes of the treatment accelerator [3–4]. The dosimetric treatment planning methods is mainly based on computer simulations [4]. The presence of the materials with different densities allows to trigger the interaction of the electron beam with human tissue. It enables phantoms for experimental methods of the medical procedures planning to develop. For these purposes it is necessary to have the method of tissue-equivalent materials for the human body phantom production. Such requirements are met by rapid prototyping technology [9].

One solution for the electron beam filters and the human body phantoms production can be the creation of filaments with the particular densities for 3D-print methods [9–10].

In this investigation one of the most common types of the clinical linear accelerator “Elekta Synergy System” is taken as electron-emitting source. The electron beam energies were selected according to the accelerator operating mode – 6 MeV, 12 MeV, or 20 MeV. For the test material the ABS-plastic doped with different concentrations of lead and zinc was chosen.

The characteristics of the electron beam interaction with the test material were calculated by Monte Carlo method.

2. Materials and methods

2.1. Test materials

For the numerical simulation the test material densities were selected according to the real anatomical structures density. For example, bone tissue density approximately equal to 1.75 g/cm^3, skin density approximately equal to 1.1 g/cm^3, muscular tissue density approximately equal to 1.06 g/cm^3 [12, 13].

In this investigation, as test materials we were used the ABS-plastic doped with different concentrations of lead and zinc. The estimation of the test materials density was carried out by the following equation:

$$\rho = \frac{\rho_{\mathrm{ABS}} \cdot \rho_{\mathrm{Pb/Zn}}}{k(Me)\cdot \rho_{\mathrm{ABS}} + (100 - k(Me))\cdot \rho_{\mathrm{Pb/Zn}}}, \tag{1}$$

were ρ_{ABS} – the ABS-plastic density measured in this investigation (1.06 g/cm^3); $\rho_{Pb/Zn}$ – the lead density (11.34 g/cm^3) or zinc density (7.13 g/cm^3); $k(Me)$,% – the mass concentration of the metal in the test material [14].

Figure 1 shows the dependence of the test material density on the lead and zinc mass concentration obtained with the help of equation 1.

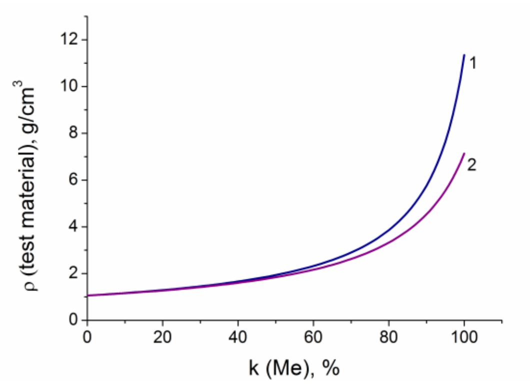

Figure 1. The dependence between the test material density and the concentration of: 1 – lead and 2 – zinc.

2.2. Emitting source

In this paper for the bases of the simulation the linear accelerator "Elekta Synergy System" was chosen as electron source. "Elekta Synergy Platform" is a radiation delivery system that integrates Image-Guided Radiation Therapy (IGRT). This accelerator allows to use leading technology in 3D conformal techniques, through static and dynamic Intensity Modulated Radiation Therapy (IMRT) to Volumetric Arc Therapy VMAT [15].

2.3. Simulation program

For the medical electron beams model, the possibility of the program "Computer laboratory (PCLab)" version 9.6 was analyzed. This software package uses the Monte Carlo method. The dose spatial distribution was calculated in the program operating mode "PHANTOM", which was created specially for the radiotherapy purposes. It allows to present energy and dose distributions in the matter for the three types of the initial particles: photons, electrons and protons. This program are modelled in the simulation the different types of physical processes, for example scattering, ionization, pair production and photoelectric effect [16].

2.4. Experiment geometry
In the simulation procedure the initial electron beam size was chosen conventionally, because the collimation system of the Elekta Synergy accelerator allows to obtain any radiation fields according to the task. The material-radiation interaction analysis was carried out in the ABS-plastic doped with different concentrations of lead and zinc. For convenience, the following parameters of the emitting source were used: the initial beam size – 2.0 mm, divergent electron beam (0.1 rad); electron energies were chosen according to the accelerator operating mode – 6 MeV, 12 MeV and 20 MeV.

3. Results and discussions
In this investigation the electron beam interaction with the ABS-plastic doped with different concentrations of lead and zinc was analyzed. For this purpose the depth dose distribution of the electron beam in the ABS-plastic doped with different concentrations of lead and zinc was calculated. The data was obtained for the three electron beam energies – 6 MeV, 12 MeV and 20 MeV. The curves are shown in Figure 2 for the test material densities equal to 1.1 g/cm^3, 1.5 g/cm^3, 2.0 g/cm^3 and 2.5 g/cm^3.

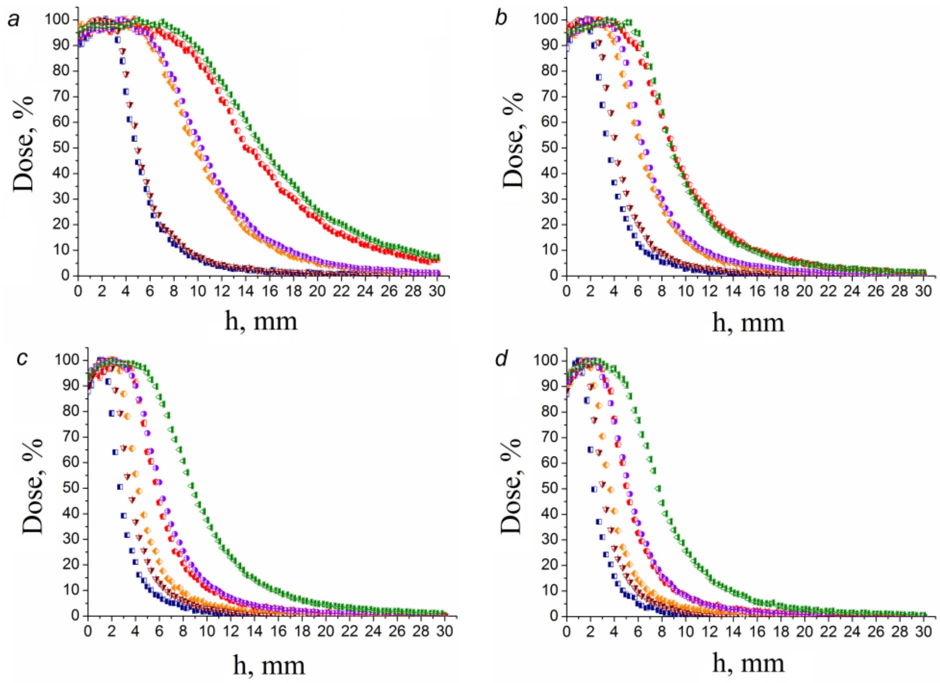

Figure 2. The electron beam depth dose distribution in the test materials with density: a – 1.1 g/cm^3; b – 1.5 g/cm^3; c – 2.0 g/cm^3; d – 2.5 g/cm^3.
The ABS-plastic modified by lead, the electron beam energy equal to:
– 6 MeV; – 12 MeV; – 20 MeV.
The ABS-plastic modified by zinc, the electron beam energy equal to:
– 6 MeV; – 12 MeV; – 20 MeV.

Figure 2 shows that minor change of the lead and zinc concentration in the ABS-plastic significantly affects on the character electron beam interaction with the test material. It is shown that, at the equal values of the test material density, the difference between the depth dose distribution curves obtained in the ABS-plastic doped with the lead and zinc increase with the growth of the electron beam energy.

Figures 3 and 4 show examples of the electron beam shapes in the transverse plane at the depth 3.7 mm in the ABS-plastic modified by lead and zinc (the test material densities – 1.1 and 2.5 g/cm^3)

for the energies equal to 6 and 20 MeV. The dose results were averaged and normalized to the maximum simulation dose in all volume of the test material.

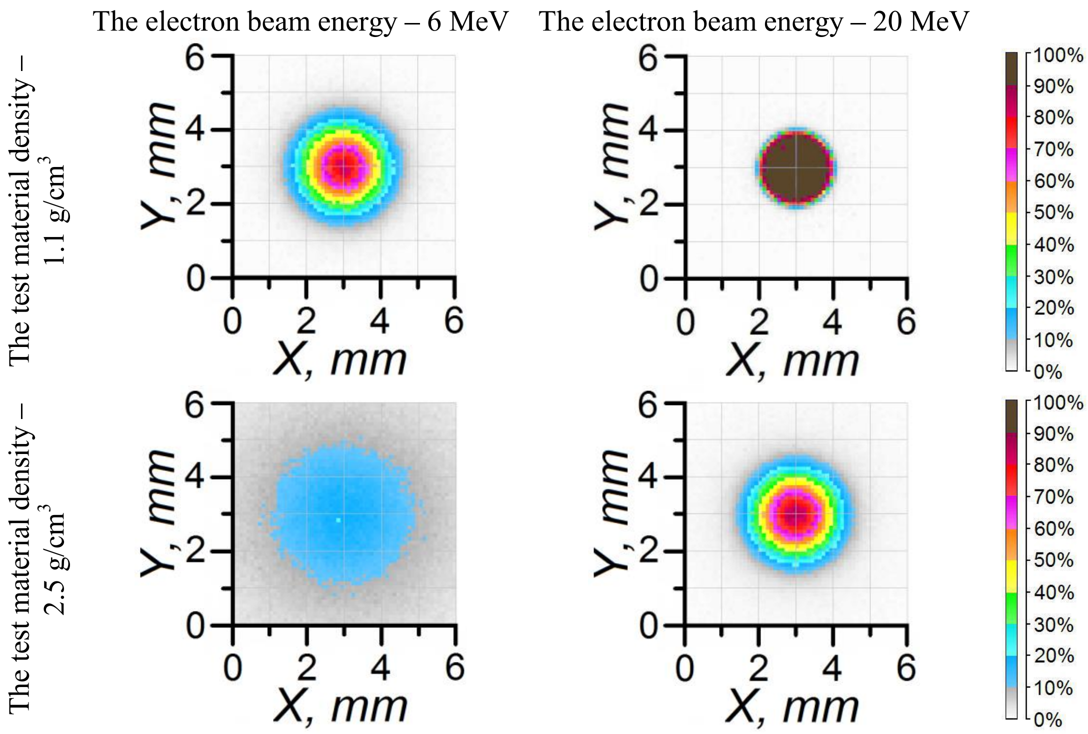

Figure 3. The electron beam shape in the transverse plane at the depth 3.67 mm in the ABS-plastic modified by lead.

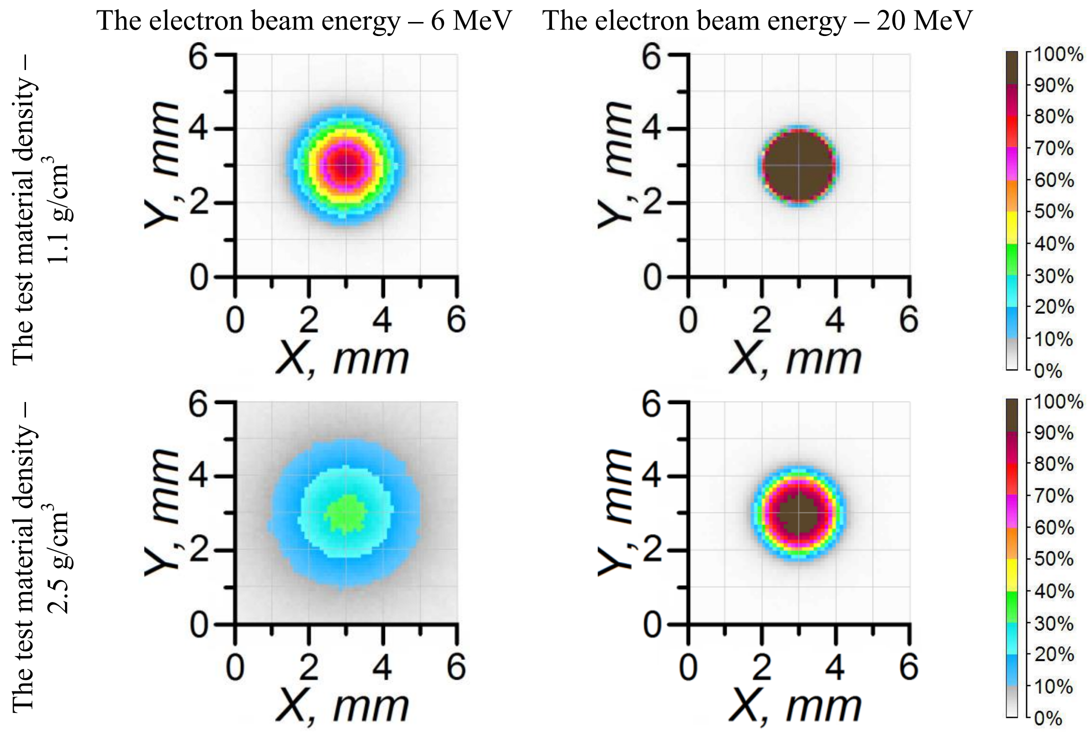

Figure 4. The electron beam shape in the transverse plane at the depth 3.67 mm in the ABS-plastic modified by zinc.

Figure 5 shows examples of the electron beam shapes in the transverse plane at the depth 3.67 mm in the ABS-plastic modified by lead and zinc (the test material density – 2.0 g/cm3) for the energy equal to 12 MeV. The dose results were averaged and normalized to the maximum simulation dose per test object.

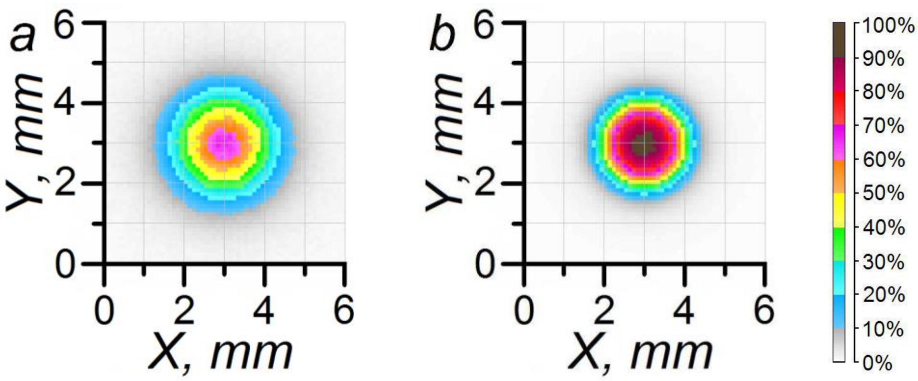

Figure 5. The electron beam shape in the transverse plane at the depth 3.67 mm in the ABS-plastic modified by a – lead and b – zinc (the test material density – 2.0 g/cm^3; the electron beam energy – 12 MeV).

The graphic data present that there is a difference in dose distribution with changing of the electron beam energy and the concentration of metal contamination in plastic. These effects are more expressed for the high electron energy and material density. It is shown that at equal density values of the test material there is a difference in the electron beam interaction with ABS-plastic modified by lead and zinc, it is conditioned by the different values of the interaction cross section.

4. Summary

The paper presents the numerical simulation results of the dose spatial distribution of the medical electron beams in ABS-plastic doped with different concentrations of lead and zinc. It is shown that the different metal contamination in ABS-plastic have an effect on the electron interaction cross section, at the equal test material density, therefore, for the human body phantom creation, it is preferred to use the Hounsfield scale for the test material instead of the mass densities.

On account of the Hounsfield's units are calculated for the X-ray interaction, further analysis of the electron beam distribution in the test materials needs additional experimental research. The purpose of a future investigation will be to modify ABS-plastic with lead and zinc rather than to obtain the Hounsfield's units and the real density of the materials.

Acknowledgements

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