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Comparison of Calculated and Experimental Depth Distributions of Gamma Radiation Doses in Polymer Media

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Abstract. The paper discusses a comparison of depth distributions of doses in plastics obtained by simulation in the PCLab software and experimentally with a Theratron Equinox–80 gamma–therapy unit. We used items made of ABS, HIPS and PLA plastics suitable for 3D printing and with different fill factors. Our study has demonstrated that the simulation results are consistent with the experimental ones within the uncertainty limits.

1. Introduction

Ionizing radiation plays an important role in the treatment of cancer by affecting malignant cells and killing them. However, irradiation has an inevitable negative effect on healthy tissues. One of the ways to increase the efficiency of irradiation is shaping the depth distribution of the ionizing radiation beam [1]. This is done using special devices called boluses. The bolus is located directly on the surface of the patient's body and makes it possible to change the depth distribution of the dose in a given direction [2].

Usually, boluses are made from tissue–equivalent materials such as wax or paraffin [3]. Such boluses can be designed as rectangular plates that overlap each other to provide the desired dose distribution. However, the obvious disadvantage of this approach is the need to place the bolus manually for each session, which may compromise the delivered dose accuracy. Also, such boluses can be made individually for each course of radiation therapy. An example of making an individual wax bolus is described in the paper [4]. The authors made a metal bolus mask using a milling machine, which was then filled with molten wax. This method to manufacture these devices is very costly and time–consuming [5].

Currently, the main advantages of 3D printing are quick and easy production of items using 3D printers, which explains the success of 3D printing in many healthcare applications, including cancer treatment [6–8]. The authors of this study previously proposed three–dimensional printing technologies to produce shaping elements for electron beam therapy [9].

This study is aimed at assessing the feasibility of 3D printing technologies in the production of individual boluses for gamma radiation therapy. Thus, the purpose of this work is to carry out a series of calculations and experiments to determine the percentage depth dose distributions in plastics used in three–dimensional printing.

2. Materials and Metods

2.1. 3D Printing and Samples

In this study, to assess depth dose distributions in 3D printed items, standard materials for fused deposition modeling were selected, namely ABS [10], PLA [11] and HIPS [12] plastics. Three–dimensional printing using fused deposition modeling makes it possible to vary the density of the produced item by varying the fill factor of the object with the material. In this study, samples were made from each material with a fill factor (k) of 80%, 90%, and 100%. The items were produced using the ORIGINAL PRUSA i3 MK3 3D printer [13]. Print parameters are shown in Table 1.

Table 1. Print parameters.

	ABS plastic	**HIPS plastic**	**PLA plastic**
Filament thread diameter, mm	1.75	1.75	1.75
Layer thickness, mm	0.3	0.3	0.3
Nozzle diameter, mm	0.4	0.4	0.4
Nozzle temperature, °C	235	235	225
Table temperature, °C	90	90	60
Print speed, mm/s	40	40	80
Air blowing of the item	Yes	Yes	No

The items were parallelepipeds with dimensions 50×50×25 mm^3. The depth of 50 mm was chosen to match the maximum thickness of boluses commonly used in medical practice.

2.2. Simulation Parameters

The simulation was carried out using the Computer Laboratory (PCLab) software version 9.6 [14] by Monte Carlo method. The simulation parameters for plastic items are presented in Table 2. The density was determined experimentally by mass method.

Table 2. Modeling parameters for test items.

Plastic	**Fill factor, %**	**Density, g/cm^3**	**Elemental composition, %**			
			H	**C**	**O**	**N**
ABS	100	1.16	56	50	44	–
	90	0.964				
	80	0.858				
HIPS	100	1.05	7.7	92.3	–	–
	90	0.945				
	80	0.84				
PLA	100	1.3	84.68	7.93	–	7.93
	90	1.17				
	80	1.04				

Fig. 1 shows the simulation geometry.

In the simulation, a cylindrical Co60 source with a diameter of 15 mm and a height of 20 mm was used as a radiation source. The average photon energy is 1.25 MeV. The source is sealed in a steel capsule with thickness of side wall 3 mm, upper end 10 mm and lower end 1 mm. The capsule is surrounded by a lead shield. The radiation passes through aperture in the primary tungsten collimator, a set of lead collimators, and enters the phantom. The distance from the source to the phantom surface is 80 cm.

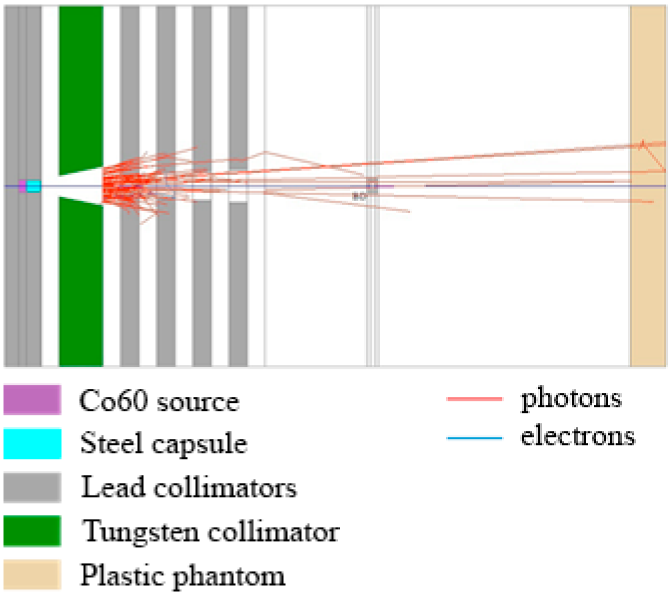

Fig. 1. Simulation geometry for calculating the depth dose distribution in the plastic phantom.

2.3. Experimental Equipment

A series of experiments was carried out with a Theratron Equinox–80 teletherapy unit [15] at the Cancer Research Institute of the Tomsk National Research Medical Centre (NRMC) (Fig. 2). The distance from the source to the surface of plastic samples was equal to 80 cm (the same as in the simulation).

Fig. 2. Irradiation of plastic samples at the Cancer Research Institute of Tomsk NRMC.

Gafchromic EBT3 dosimetry films [16] used as a radiation detector, were placed in the end geometry between plastic items. The possibility of measuring depth dose distributions in such geometry was demonstrated by the authors in [17]. After irradiation, dosimetry films were digitized using an Epson Perfection V850 Pro flatbed scanner [18] and were processed in the MatLab software [19].

3. Results and discussions

Using Computer Laboratory (PCLab) software version 9.6 [14] the calculated depth distributions of photon radiation beams in ABS, HIPS and PLA plastics with different fill factors were obtained. The calculated parameters were normalised to the maximum dose in the detector. The number of simulated primary photons was 10^5 photons for each calculation, which corresponded to a statistical error of 2%.

The simulation geometry was used to perform a series of experiments. Depth dose distributions in plastic samples were determined using Gafchromic EBT3 dosimetry films [16]. The uncertainties of dose determination by dosimetry films equal to 4% [16].

The calculated and experimental percentage depth distributions (PDD) of absorbed doses in the tested plastics are presented in Fig. 3–5.

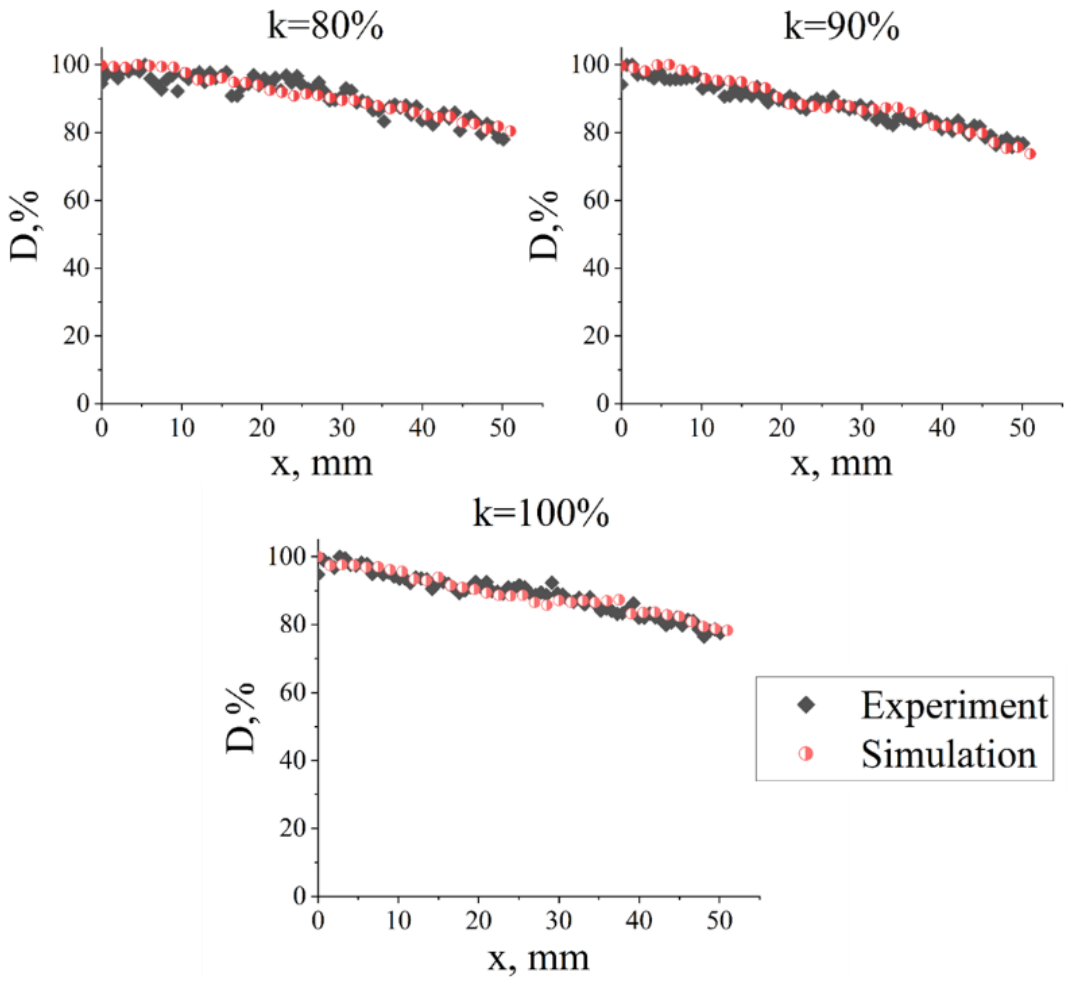

Fig. 3. PDD in ABS plastics with different fill factors *k*.

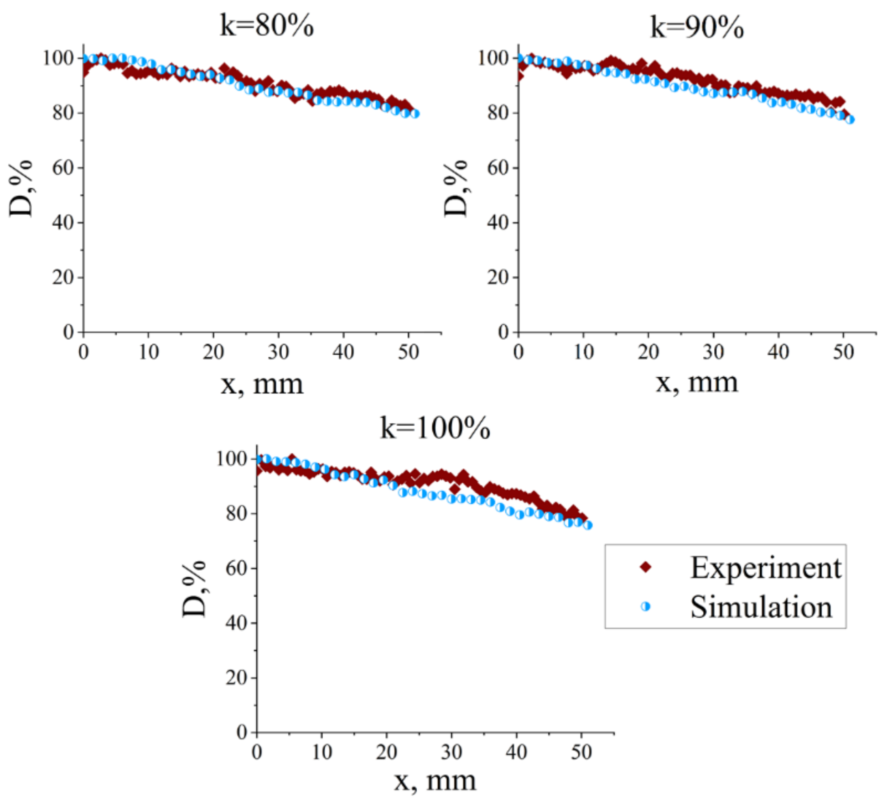

Fig. 4. PDD in HIPS plastic with different fill factors *k.*

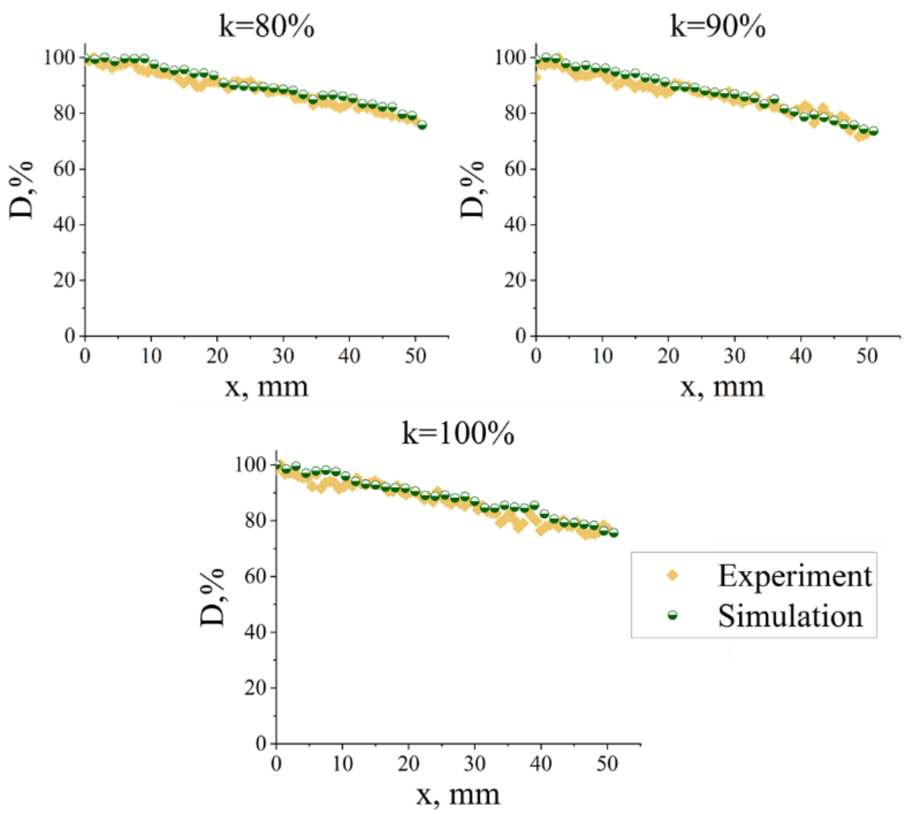

Fig. 5. PDD in PLA plastic with different fill factors *k.*

Fig. 3–5 show that the percentage dose depth distributions obtained in calculations and experiments in the tested plastics coincided within the error limits. Thus, the numerical model can be further used to select the geometric parameters of boluses for solving specific problems.

The results of the work showed that all tested plastics, ABS, HIPS and PLA, can be used to produce boluses for gamma radiotherapy. Each plastic makes it possible to shift the maximum dose up to about 80%. A change in the fill factor from 80% to 100% does not have a significant effect on the curves obtained (the difference between dose values in 5 cm plastic depth with different fill factors does not exceed 3%).

4. Conclusion

In this study, a series of calculations and experiments were carried out to determine the percentage dose depth distributions in plastics suitable for 3D printing by fused deposition modeling. Items made of ABS, HIPS, and PLA plastics with different fill factors: 80%, 90%, and 100% were used in the study. The calculated and experimental data coincided within the error, suggesting that created numerical model could be used for selecting geometric parameters of boluses depending on their intended purpose.

The results of this study demonstrate the applicability of all studied plastics for the production of boluses for gamma radiotherapy.

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