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RESEARCH OF X-RAY TUBE ENERGY CHARACTERISTICS

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ИССЛЕДОВАНИЕ ЭНЕРГЕТИЧЕСКИХ ХАРАКТЕРИСТИК РЕНТГЕНОВСКОЙ ТРУБКИ

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Аннотация. *В настоящей работе приведены результаты исследования энергетических характеристик рентгеновской трубки Xstrahl300 путем моделирования процесса переноса тормозного излучения методом Монте-Карло, на котором основаны алгоритмы расчёта программы PC LAB. Показана возможность оценки распределения поглощенной дозы в различных точках координат водного фантома используя математическую модель. Таким образом, могут быть найдены оптимальные условия эксплуатации рентгеновской трубки в лучевой терапии при различных локализациях. Кроме того, математическая модель рентгеновского излучения способна моделировать ожидаемую эффективность проводимой терапии и относительную биологическую эффективность, используя теоретические модели.*

Introduction. Research on modification of radiotherapy methods using agents introduced into the tumor is being carried out in many countries in order to increase the relative biological effectiveness (RBE) therapy[1]. It has been shown [2,3] that with the introduction of heavier elements with an atomic number $Z \geq 53$ into the tissue, the energy release increases. The most frequently used elements are radiosensitizers, chemotherapeutic agents, and nanoparticles of platinum and gold [2,3,4]. A special attention should be given to the theory of photon-capture interaction [1]. The interaction between photons and nuclei of heavy elements ($Z \geq 53$) results in a generation of a large number of the characteristic X-rays and low-energy auger electrons. This secondary low-energy radiation ionizes nearby atoms and leads to the occurrence of series of highly active radicals, which causes the destruction of the macromolecules of DNA and RNA, proteins, cells, and other structures. If the agent is introduced into the tumor cell (cell nucleus or other tissues and organs), the process may significantly increase the likelihood of death of the tumor cell. The study of X-ray tube energy characteristics will allow creating mathematical models that will calculate the spectra of photons and the dose distribution at various points in the water phantom. Thus, the optimal conditions of using an X-ray tube for different locations can be selected. This work aims to examine energy characteristics of radiotherapeutic apparatus Xstrahl300 by creating a model bremsstrahlung transfer on the Monte Carlo method with the purpose of further evaluation of the photon-capture interactions.

Materials and methods. The important part of this research is the use of an X-ray tube, which generates orthovoltage photons with a sufficiently high dose rate. The Tomsk Regional Oncology Center has an X-ray tube Xstrahl300 (fig. 1a), which allows producing bremsstrahlung in the tube voltage range from 60 to 300 kV.

a) system Xstrahl300 b) dosimetry Dose-1 c) FC65-G d) Blue Phantom

Fig. 1. The radiotherapeutic system Xstrahl300 and equipment for dosimetry

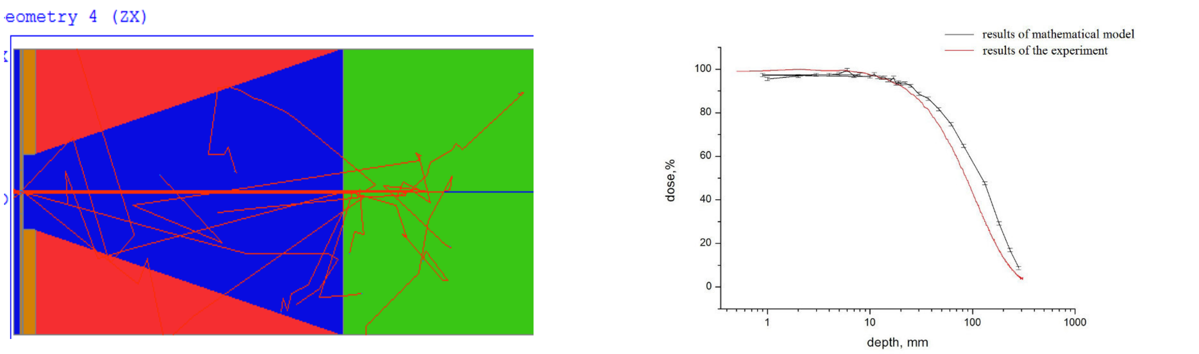
The system Xstrahl300 has applicators, which form the radiation field. Therapeutic applicators are made from copper and have tips made from perspex for visual control. Filters are used to absorb low-energy spectrum of photons, thereby reducing the radiation dose to human skin. Filters are constructed of metals of different thicknesses giving in total a thickness of the half-attenuation layer (HAL) for a certain energy bremsstrahlung. The clinical dosimetry Dose-1 (fig. 1b) was used as a measuring device. The device in conjunction with the ionization chamber FC65-G (fig.1c) was used for accurate measurement of the absolute doses in accordance with the recommendations of IAEA #398. All measurements were carried out in a water phantom Blue Phantom (fig.1d). It is common knowledge that water is the reference standard for clinical dosimetry, since water density corresponds to the density of human tissues and organs. In compliance with the international dosimetry protocols TG-61[5] and the TRS-398[6], calculation of the absorbed dose in water DW, Q is carried out relying on the data measured by the ionization chamber, and is defined as follows:

$$D_{W,Q} = M_Q \times N_{D,W,Q_0} \times k_{Q,Q_0} \quad (1)$$

where M_Q - is the reading of the dosimeter with the reference point of the chamber positioned at z_{ref} in accordance with the reference conditions, and corrected with regard to the influence of such quantities as temperature and pressure, polarity, and electrometer calibration, C; N_{D,W,Q_0} - is the calibration factor in terms of absorbed dose to water for the dosimeter at the reference quality Qo; k_{Q,Q_0} - is a chamber specific factor, which corrects differences between the reference beam quality Qo and the actual beam quality being used, Q.

Modeling of the process of bremsstrahlung transfer to water was performed using the program «Computer Lab» (PCLab) version 9.7.[7], which is based on software package EPHCA (electron-photon cascade) and designed for modeling of processes of propagation of electrons, positrons, protons, and photons using the Monte Carlo method.

Results and discussion. The distribution of absorbed dose in depth in the water phantom was measured in increments of 1 mm. Absorbed doses in the water phantom points using the formula (1) were calculated. The model was created taking into account the precise geometrical parameters of the system Xstrahl300 (fig. 2a). The barriers and filters, which overcome the bremsstrahlung on the way to the main absorber (phantom), were taken into account in this research. As a result, any additional error results of the mathematical model were avoided. Figure 2b is a graph comparing the experimentally measured results with results of the theoretical model of absorbed dose values. The data analysis shows that the values of the absorbed dose turned to be practically the same in the field of maximum energy transfer. Maximum energy transfer was found at a depth of about 6 mm (99,6% ± 0,74% dose) for mathematical model results and 5.9mm (99,6% ± 2% dose) for experimental results correspondingly. The discrepancy between the experimental and theoretical values of absorbed dose increases in progress passing bremsstrahlung in the water phantom. This occurs due to the contribution of scattered radiation, which was not taken into account in the theoretical model.



a) geometry of the mathematical model b) the distribution of the absorbed dose in the depth of the phantom

Fig. 2. Results of experiment

The obtained results can be considered quite acceptable for the description of the interaction processes of bremsstrahlung generated by the X-ray tube. Thus, the optimal X-ray tube operating conditions (in terms of the photoelectric effect in the contrast agents) for different locations can be found. In addition, mathematical models of the X-ray enable us to simulate the expected effectiveness of the therapy and the RBE using theoretical models.

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