Properties of absorbed dose distribution in heterogeneous media

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Abstract. Accuracy of calculation of the absorbed dose spatial distribution into patient body is an important task in the radiation treatment of cancer. The correct calculation determines radiotherapy effectiveness. Thus, researches are improving calculation methods permanently to achieve running speed and accuracy increasing of used algorithms of calculation routines. The algorithms of routines for calculations of absorbed dose radial distributions into homogenous and heterogeneous medium irradiated by directional source of photons are described in the presented work [1,2].

Preceding calculations of an absorbed dose distribution were carried out in electron equilibrium approximation, i.e. without taking into account of generation and secondary electron transfer events [3]. However, now the approximation is inadequate in most cases, therefore the calculations are carried out by means of routine which based on Monte Carlo method with taking of the events into consideration [4].

The results of the dose calculation in water phantom are presented at the Fig. 1.

Presented isodose curves are laying in plane which passing through axis of symmetry of photon beam [5]. Lateral dose distribution drastically declines near the beam boundaries because of photons leak from direct view of source. Additional calculations show that it is convenient to present the dose produced by thin photon beam as a sum of two terms. First of one is conditioned by secondary electrons, which produced by nonscattered photons in first act of collision with atoms of substance. Second term is contribution of multiple scattered photons. These contributions have different cross-sections and gradients. First term is a dominant
one in a volume which has secondary electron run length order dimension. Second term contribution is a major one at long distances from axis of photon beam.

In the work is shown that dose calculations accuracy and the routine running speed may be improved significantly in the case of separate calculation the terms and taking into considerations symmetry of the task and specific properties of scattered and nonscattered radiation. Absorbed dose distribution via distance to beam axis for different depth (3, 5 and 10 cm) is presented at Fig. 2.

**Figure 2. Radial absorbed dose distribution from a point collimated source of photons for different depth (3, 5 and 10 cm).**

radiation fields’ distribution in a point is usually calculated by Monte-Carlo method as a ratio of absorbed energy in a small volume to mass of the volume. However, this way of the dose calculation gives correct result if the ratio limit does not become infinite at $V \rightarrow 0$. In the considerable task both first and second terms of calculated dose become infinite at the photon beam axis. Therefore the calculation deserves some assumption.

Results of calculation of radial distribution absorbed dose produced by line source of Compton electrons produced in water by nonscattered 1.25MeV photons are presented at the Fig. 3. The calculations were carried out with GEANT 4 (Release 6.1) software [4].

**Figure 3. Absorbed dose radial distribution produced by line source.**

The presented at the Fig. 3 data confirms $1/r$-type dependence of absorbed dose via radius for line source of electrons. One can see, that the product $rD(r)$ changes enough slightly at $r \rightarrow 0$ and so it is possible to take $r$-step in radial distribution histogram enough wide for collection easing of statistical data.

Calculation of absorbed dose distribution should be carried out taking into account topography and anatomy of human body, geometry of irradiation and specific effect of different types of ionizing radiation in tissues for. This sort of specific task is...
absorbed dose distribution calculation in a body having artificial heterogeneities in tissues such as implant.

It is obvious that implant placed into irradiated area is perturbing spatial dose distribution. It is impossible to realize correct radiation exposure dose planning of postoperative radiotherapy without taking into consideration this perturbation effects.

The results were obtained for isotropic source of photons with energy 1.25 MeV having different collimations angles. Cylindrical water phantom with the nickel-titanium alloy slab, installed at a certain depth, has been exposed by the source.

Absorbed dose values at the conic photon beam axis are presented at the Fig. 4. Collimating angle is 4.96°. NiTi layers are placed at 3 and 10 cm depth.

![Figure 4. Absorbed dose values at the conic photon beam axis in the water phantom (histogram) with NiTi layers (points).](image)

Calculations show that the dose on the beam axis rapidly rises near the front phantom boundary due to increasing of secondary electrons knocked out by photons. The maximum of the dose is at the depth corresponding to the maximum range for the secondary electrons. For greater depths comes quasi-equilibrium state, and the dose slowly decreases due to attenuation of the photons flux [6].

The dose value rises near front surface of metal due to reflection from metal surface of secondary electrons produced in water and due to reverse electron current. The reverse current appears when electrons produced in metal undergo intensive scattering into metal due to large charge of its atoms. Usually thickness of the metal layer is greater than the run lengths of secondary electrons, thus dose formed beyond the metal is determined by electrons, which were knocked out from metal and leave it due to multiple scattering process. But forward current of secondary electrons in metal is less than forward current in water because of more intensive scattering in metal and because of lesser electron run lengths for high Z substance. Due to this fact, the dose declines near the rear edge of the metal slab.
However, the dose may be higher behind metal in comparison with dose into homogenous water phantom if a secondary electron run length exceeds metal layer thickness. Of course, variation of dose field caused by metal layer is observed at a distance when compared to the range of secondary electrons.

Taking into account enlarged dose value at tissue-implant boundary area in comparison with dose in homogenous tissue at the same depth may be recognize as necessary when drastic course of radiotherapy treatment required of irradiation with maximum or near-maximum permissible dose. It concerns a case when surgical operation injured tissue is exposed by irradiation and therefore the tissue has enlarged probability of radiation injury. But dose enlarging into heterogeneous volume is not an obstacle for postoperative radiotherapy of tissue implanted by NiTi as it may strikes of residuary cancerous cells behind the implants more effective. However, tolerance level of the tissue which is subjected to surgical operation and contacted with NiTi implant should be obtained more specific at clinical trials condition.

References
[1] E.N. Donskoy, V.A. Klimanov, V.V. Mesherin et all., Med Phys. 4 (1997) 38.
[2] R. Mohan, C. Chui, L. Ludofsky. Med Phys. 13(1) (1986) 64.
[3] V.G. Zolotuhin, L.R. Kimel, A.I. Ksenofontov et all., Radiation field induced by the point monodirectional photon source. M., Atomizdat (1974) (in russian).
[4] S. Agostinelli, J. Allison, K. Amako et all. GEANT 4 – a simulation toolkit. Nucl. Instr. and Meth. A 506 (2003) 250.
[5] R. Brun, F. Rademakers et all. ROOT – an object-oriented data analysis framework. Users guide. Geneva, CERN (2003).
[6] A.M. Kolchuzhkin, V.V. Uchaykin. Introduction to the theory of penetration particles through matter. M., Atomizdat (1978) (in russian).