DOSE DISTRIBUTION IN THE HETEROGENEOUS MATERIALS IRRADIATED BY ELECTRON BEAMS

I. Kaluska[b]***, V.T. Lazurik***[a]***, V.M. Lazurik***[a]***, G.F. Popov***[a]***, Y.V. Rogov***[a]***, Z. Zimek***[b]

[a]***Kharkov National University, Kharkov, Ukraine;***

[b]***Institute of Nuclear Chemistry and Technology, INCT, Warsaw, Poland;***

E-mail**:** ***popov@univer.kharkov.ua***

The simulation of the absorbed depth-dose distribution (DDD) near the boundary of contacting materials with a different density and/or by effective atomic numbers of materials irradiated by a scanning electron beam was fulfilled. The experimental validation of the obtained theoretical predictions related with abnormal behavior of the DDD in heterogeneous materials was fulfilled on the radiation-technological lines with Linac LAE 13/9, INCT.

PACS: 81.70.-q

1. INTRODUCTION

The numerical investigations of a dose distribution in heterogeneous targets irradiated on radiation-technological lines (RTL) by a scanned electron beams on moving conveyer were carried out with use of software ModeRTL [1]. The software ModeRTL (Modeling of the Radiation-Technological Line) is developed for simulation of radiation processes and calculation of the absorbed dose, temperature, and charge distribution within products irradiated by a scanning electron beam with the electron energy range from 0.1 to 20 MeV on industrial RTL.

Investigations were fulfilled in the two-dimensional geometrical model, in which the target on a conveyor line was represented as a set of parallelepipeds unlimited on length along a motion of the conveyor (axis Z). It is supposed, that the parallelepiped sides are oriented only in parallel and perpendicularly to scanning direction of an electron beam (axis Y), and the material of each element of target (represented as separate parallelepiped) is homogeneous. Dose fields in a plane of scanning of an electron beam (plane XY) were calculated. Depth-dose distributions (depth is measured from an irradiated surface of object along an axis X perpendicular to axis Y) were compared on various distances from a boundary of materials with different densities and/or atomic numbers.

The comparison and analysis of the results have allowed one to bring out a series of features in behavior of dependence of a depth-dose distribution near to boundary of two different materials. Let us note, that an anomaly dose which appear near the boundaries of two materials with different atomic numbers are well known. As a rule, the consideration of these effects is perform for a case of normal falling of an electron beam and at a uniform irradiation of a boundary of contacting materials, i.e. in one-dimensional model. In this case, the influence of density of the contacting materials on value of boundary effects can be neglected. This report is focused mainly to boundary effects of another sort, namely, boundary effects appearing due to difference of densities of contacting materials.

2. THEORETICAL PREDICTIONS

The heterogeneous target consisting of two blocks was chosen for an illustration of some theoretical predictions, obtained on the basis of results analysis of computer experiments. Blocks of contacting materials have identical chemical composition and different densities. For example, such target can be easily implemented with use of homogeneous (PE density of 0.94 g/cm^3) and granules (PE2 bulk density of 0.3 g/cm^3) polyethylene. The geometrical parameters of a target were chosen so that the curves of depth-dose distribution at center of blocks corresponded to an extreme case of a semi-infinite target. It is implemented when the sizes of blocks greater than r_0 – continuous slowing-down approximation range of electrons in material of the block.

The key features of simulation results of an electron dose distribution in targets consisting of two materials with different density are the following:

1. Depth-dose distribution near to boundaries of the contacting materials with different density differs under the shape from a depth-dose distribution in semi-infinite target for each of contacting materials.
2. The values of doses near to boundary of two materials which differed only in density coincide on a surface of a target and can differ in depth of a target,
3. The value of a dose in material with smaller density is greater than in material with greater density on all depth of an irradiated target,
4. Maximal values of a dose near to a boundary of the contacting materials with different density can exceed maximal values of a dose in semi-infinite target for each of contacting materials,
5. The local minimum in depth-dose distribution can appear on small distances from a surface of a target in material with greater density,
6. Depth-dose distribution near to boundaries of contacting materials with different density have the similar shapes on considerable distances from a surface of a target.

The theoretical analysis of mentioned above general features allows to make a conclusion about a determinative role of electrons, which move along boundary, in process of formation of a boundary effect.

It is important for development of theoretical models to utilize an experimental validation of basic features of boundary effects predicted on the basis of computer simulation of an irradiation process. The quality of an irradiation process in radiation technologies are determined by values of the dose limits - D_{min} and $D_{max.}$ The practical recommendations and conclusions obtained on the basis of the mentioned above basic features of boundary effects are important for radiation technologies. Thus, the theoretical predictions require experimental validation on actual RTL.

3. EXPERIMENTAL

The experimental investigations of the absorbed depth-dose distribution near to boundary of two materials with different density and/or by effective atomic number which were irradiated by a scanning electron beam with energy 10 MeV were fulfilled. The absorbed dose for irradiated materials was delivered in the range of 40…60 kGy. The experiments were performed on the RTL with Linac LAE 13/9 at the INCT, Warsaw, Poland [2]. Dose effects near to boundary of two contacting materials with different density and atomic number such as Al with density 2,7 g/cm^3, high density polyethylene (PE) block with density 0.94 g/cm^3, PE1 granules with bulk density 0.66 g/cm^3, and wood with density 0,44 g/cm^3 were investigated. The materials were represented as parallelepipeds at which the contacting boundaries are in parallel with an axis of electrons beam. Cellulose Triacetate (CTA) dosimetric film (FTR-125) with thickness 0.125 mm, density 1.32 g/cm^3 was used for measurement of a depth-dose distribution.

4. RESULTS AND DISCUSSION

Results of the specially carried out dose distribution measurements in CTA films inserted in the standard Al dosimetric wedge (the points) and obtained with use of the software ModeRTL (histograms) are presented in Fig.1,a. Results of Monte Carlo simulation of the depth-dose distributions in homogeneous materials (histograms with points +) and obtained by semi-empirical model [3] for semi-infinite medium (dash line) are presented for comparison in Fig. 1,a,b.

As it is seen from Fig. 1,a, the ratio of calculated values of a dose in CTA film to a dose in Al on a surface of a target (x=0, see values in the first cells of two histograms) corresponds to the ratio of values of a dose measured by Al dosimetric wedge (Experiment 1) to calculated values of a dose in Al (histogram with points +) on any depth in a target.

Difference of a dose profile in a CTA film from a dose profile in target material are determined by two factors: by change of a dose profile due to differences of stopping powers of materials (first factor) and change of a dose profile due to differences of materials density (second factor).

The smaller density and greater stopping power of CTA film material relatively Al corresponds to a case, when both factors work in one direction, that lead to considerable excess of a dose distribution in CTA films relatively a dose in Al (greater than 20%). The difference in density of a film material and the target materials lead to appreciable distortion of a dose profile in a film (compare curves of a dose - measured by Al dosimetric wedge (Experiment 1) and calculated (or measured) in CTA films).

It essentially distinguishes a case, when there is a difference in densities of contacting materials from a case, when there is a difference only in stopping powers of material.

The conclusions formulated on the basis of the visual analysis presented on Fig.1,a are agreed with experimental and simulation results for PE granules (See Fig. 1,b). The ratio of a stopping power of CTA film material to a stopping power of PE is less than 1 and density of CTA film material more than PE density.

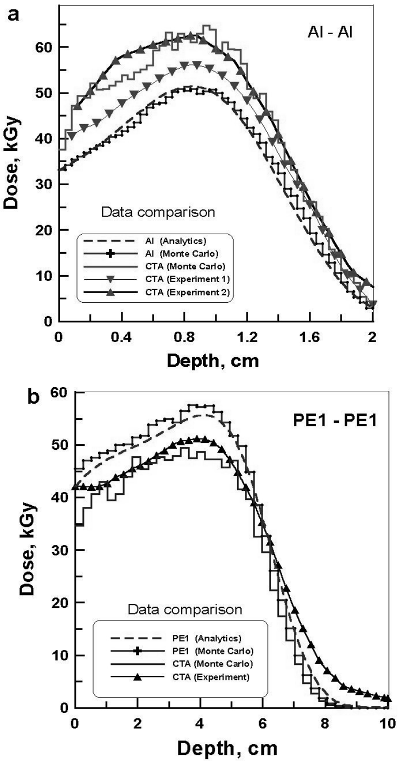

Fig.1. Depth-dose distribution in the target consisting of two Al blocks (a) and PE1 blocks (PE1 density 0.66 g/cm^3) (b): Histograms - results of calculations by a method Monte Carlo of the dose distribution in Al and PE1 blocks (points +) and in CTA film placed between two Al and PE1 blocks; Dashed line - dose distribution calculated with the use semi-empirical model at the center of Al and PE1 blocks. Experimental results for dose distribution measured by CTA film placed between two Al and PE1 blocks are shown by points

Differences of a dose profile in a CTA film from a dose profile in bulk PE are determined by two factors, as well as for a case of CTA film in Al. However, in this case, action of the factors is opposite and the values of difference of doses in CTA film and in bulk PE less on an absolute value and has an opposite sign.

Results of Monte Carlo simulation (histograms) of the depth-dose distributions on the boundary of two contacting blocks consisting of different materials and obtained by semi-empirical model for semi-infinite medium (solid line) are presented in Fig. 2,a and b.

Experimental results for depth-dose distribution measured by CTA film placed between materials with different density in Fig. 2,a and b are shown by points. The relative accuracy of experimental data did not exceed 5% for values of doses greater than 10 kGy. The uncertainty of the depth value of all curves is 0.125 cm and the average size in each point is 0.1см. It is supposed, that the process of an irradiation can be described in one-dimensional model, i.e. the effects of lateral boundaries of a target can be neglected.

The requirements for experiments and computer modeling were chosen so that in dedicated range of depths the level of precision for an experimental and calculation data (relative deviation) of measuring no greater than 5%, relative root-mean-square statistical error no greater than 5%) was supplied sufficient for carrying out of the comparative analysis.

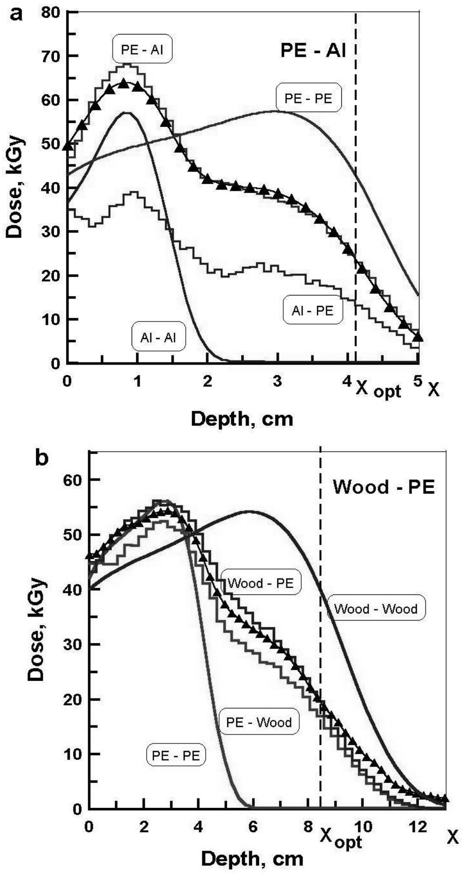

Fig.2. Depth-dose distribution in the target consists of PE-Al (a) (PE density 0.94 g/cm^3) and wood-PE blocks (b) (wood density 0.44 g/cm^3): Histograms – results of calculations by a method Monte Carlo of the depth-dose distribution near to boundary of Al, PE, and wooden blocks; Solid curves – depth-dose distribution at the center of Al, PE, and wooden and PE blocks calculated with the use semi-empirical model. X_{opt} is the optimum target thickness for PE and wooden blocks at one-sided irradiation respectively

As it is seen in Fig.2,a and b in dedicated range of target depths the measurement results are satisfactorily agreed with results obtained on the basis of simulation of an irradiation process by a Monte-Carlo method.

It is possible to conclude, that basic features of boundary effects which were described in items 1,3,4,6 (part «Introduction») obtained theoretically with using the software ModeRTL are experimentally validated. The established fact of strong distortion of a dose profile in thin dosimetric film (see Fig.1,a and b) specifies necessity of modernization of a measurement principles for experimental validation of items 2,4 for the list of general features of boundary effects.

The results represented in Fig.2,a and b concerned to a case when the sizes of the contacting materials in a direction perpendicular to a boundary of target are great and it is possible to suppose a target by unlimited.

5. CONCLUSIONS

The experimental and theoretical examinations of boundary anomalies of a dose distribution are performed on model samples. Both used materials (Al, PE, wood, CTA film) and radiation facility on basis of the LAE 13/9 are typical for a series of radiation technologies. As it is seen from comparison of experimental results with data, obtained by simulation methods, follows, that the theoretical predictions of behavior of a dose near to a boundary of two materials with different density are correct. It was established, that the boundary anomalies of a dose can be realized at radiation processing of heterogeneous materials. Investigation of those anomalies can be used to estimate the quality of an irradiation fulfilled on RTL.

It is shown that an application of designed software model for planning of irradiation on RTL and interpretation of results obtained by dosimetric film is correct, is useful and, in a series of cases it is necessary in practice.

REFERENCES

1. V.T. Lazurik, V.M. Lazurik, G. Popov, Yu. Rogov. *Proc. of EBT'03 Conf. Varna, Bulgaria*, p.616-622.
2. Z. Zimek, S. Kołyga, V.M. Levin, V.M. Nikolaev, V.V. Rumyantsev, L.P. Fomin. An Institute of Nuclear Research Electron Linac. // *Nukleonika,* 1972, v. 17, № 1-2, p. 67-75.
3. V.M. Lazurik, T. Tabata, V.T. Lazurik // *Radiat. Phys. Chem.* 2001, v. 60, p. 161-162.

РАСПРЕДЕЛЕНИЕ ДОЗЫ В ГЕТЕРОГЕННЫХ МАТЕРИАЛАХ, ОБЛУЧАЕМЫХ ПУЧКАМИ ЭЛЕКТРОНОВ

И. Калуска, В.Т. Лазурик, В.М. Лазурик, Г.Ф. Попов, Ю.В. Рогов, З. Зимек

Проведено моделирование распределения поглощенной дозы (РПД) на границе раздела веществ с различными плотностями и/или атомными номерами, облучаемых сканирующим электронным пучком. Экспериментальную проверку теоретических предсказаний аномального поведения РПД в гетерогенных материалах проводили на радиационно-технологической линии с линейным ускорителем электронов LAE 13/9, ИЯХТ, Варшава, Польша.

РОЗПОДІЛ ДОЗИ В ГЕТЕРОГЕННИХ МАТЕРІАЛАХ, ЩО ОПРОМІНЮЮТЬСЯ ПУЧКАМИ ЕЛЕКТРОНІВ

І. Калуска, В.Т. Лазурік, В.М. Лазурік, Г.Ф. Попов, Ю.В. Рогов, З. Зімек

Проведено моделювання розподілу поглиненої дози (РПД) на границі контактуючих матеріалів з різними щільностями і/чи атомними номерами, що опромінюються скануючим електронним пучком. Експериментальну перевірку теоретичних передбачень аномальної поведінки РПД у гетерогенних матеріалах проводили на радіаційно-технологічній лінії з лінійним прискорювачем електронів LAE 13/9, ІЯХТ, Варшава, Польща.