

## COMPARISON OF DOSE DISTRIBUTION PREDICTION IN TARGETS IRRADIATED BY ELECTRON BEAMS WITH DOSIMETRY

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### Abstract

The features of the absorbed depth-dose distribution (DDD) on boundaries of two contacting materials and material with air irradiated by an electron beam (EB) were predicted by simulation with the software ModeRTL (Modeling of the radiation-technological lines). Validation of DDD prediction with dosimetry was fulfilled on the industrial radiation-technological line (RTL) with linear electron accelerator LAE 13/9 at the INCT, Warsaw. Simulation and measurement of boundary effects of DDD were carried out for targets irradiated by scanned EB with energy 10 MeV on moving conveyer. The physical regularities for DDD on the boundary of contacting materials predicted by simulation methods were experimentally confirmed.

### INTRODUCTION

For all radiation-technological processes, one of the most important characteristics is the absorbed dose of electrons in an irradiated materials. For each product to be treated in the irradiation facility, there will usually be a minimum dose limit  $D_{min}$  to obtain the desired effect and a maximum dose limit  $D_{max}$  that the product can tolerate without degradation in quality [1]. Value of an absorbed dose of electrons necessary for realization of the EB processing, the required level of dose uniformity ratio ( $DUR = D_{max}/D_{min}$ ) in volume of the irradiated product determine efficiency and productivity of the technological process.

In various EB technologies, location and value of  $D_{min}$ ,  $D_{max}$ , and DUR essentially depend on boundary anomalies in depth-dose distributions, which appear under irradiation of heterogeneous targets [2,3]. For example in practice, such boundary anomalies appear under irradiation by EB of contacting materials (solid/liquid) with different densities and/or atomic numbers, near the boundary of irradiated materials with package and with air, on the boundary of irradiated materials with materials of body dosimeter, etc. Theoretical and practical investigation of those anomalies is necessary in practice to estimate the quality of an irradiation performed on RTL at realization of various industrial EB processing.

Results of simulation and measurement of the location and value of maximum and minimum doses, the features for the absorbed dose distribution near the boundaries of two contacting materials at orientation in parallel with incident electron beam are discussed in the report.

### MODELING OF BOUNDARY EFFECTS

Simulation of a dose distribution in heterogeneous targets irradiated on radiation-technological lines by a scanned electron beams on moving conveyer were carried out with use of ModeRTL software [2]. The ModeRTL (Modeling of the Radiation-Technological Line) software was developed to simulate radiation processes and calculate the absorbed dose, temperature, and charge distributions within products irradiated by a scanning electron beam with electron energy range from 0.1 to 25 MeV on industrial RTL. The ModeRTL uses in the unified calculation scheme for the transport of electrons in materials of different calculation methods, such as analytical, semi-empirical, and precise - method Monte Carlo. It provides high veracity of simulated results and decisions accepted on this base.

Simulation of EB dose distributions in an irradiated heterogeneous target was fulfilled in two-dimensional (2-D) geometrical model. The 2-D dose distribution in the target is represented as function of two coordinates - of the target depth (axis X) and the target width along scan direction (axis Y). Conveyer moves along axis Z. Such conditions are realized in many cases for EB processing when the target is irradiated at one- and double-sided on the moving conveyer.

The heterogeneous target on a conveyer line was represented as a set of parallelepipeds unlimited on length along a motion of the conveyer (axis Z). It is supposed, that the parallelepiped sides are oriented only in parallel of each other, and the material of each element of the 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 the incident surface of target 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. Dosimetric film was modeled as thin sheet unlimited on length inserted in parallel axis of EB between the contacting homogeneous materials in plane XZ.

Dose effects near the boundary of two contacting materials with different density and atomic number such as Al with density  $2.7\text{g/cm}^3$ , high density polyethylene (PE) block with density  $0.94\text{g/cm}^3$ , PE1 granules with bulk density  $0.66\text{g/cm}^3$ , wood with density  $0.44\text{g/cm}^3$ , and air were investigated.

Comprehensive analysis of simulation results of the depth-dose distribution of electrons near the boundary of two materials at orientation in parallel with incident

electron beam allows to formulate the following basic regularities for an electron dose distribution:

1. The boundaries effects for the electron depth-dose distribution of contacting materials with different density and/or atomic number are mainly determined by difference in materials density.
2. Depth-dose distribution of electrons near the boundaries of the contacting materials with different density differ in the shape from a depth-dose distribution in semi-infinite target for each of contacting materials.
3. The values of doses near the boundary of two materials which differ only in density coincide on the incident surface of a target and can differ in depth of a target.
4. The value of an absorbed dose in material with smaller density is greater than in material with greater density on all depth of an irradiated target.
5. Maximal values of an electron dose near the boundary of the contacting materials with different density can exceed maximal values of a dose in semi-infinite target for each of contacting materials.
6. The local minimum in depth-dose distribution can appear on small distances from a surface of a target in material with greater density.
7. Depth-dose distribution of electrons near the boundaries of contacting materials with different density has the similar shape on considerable depth from the incident surface of a target.
8. The shape and value of the depth-dose distribution of electrons near the boundary of contacting materials with essentially different densities are very sensitive to the orientation of lateral face of irradiated materials relatively to axis of electron beam, as well as to angular spread of EB.

The theoretical analysis of mentioned above general regularities allows draw a conclusion about a determinative role of electrons, which move along boundary, in the process of formation of a boundary effects for depth-dose distribution. It means, that performing simulation of trajectories of electrons in irradiated target, the special attention should be given to the transverse displacements of an electron.

## COMPARISON WITH DOSIMETRY

The boundaries effects on the depth-dose distribution at irradiation with EB of contacting materials for two practical cases are considered. In the first case, the width for one of contacting materials  $Y_i$  in plane XY of EB scanning is essentially less than  $(r_0)_i$  for this materials, i.e.  $Y_i \ll (r_0)_i$ . Where  $r_0$  is continuous slowing-down approximation range of electrons in material. For example, such conditions are implemented on the boundary of irradiated materials with package. In the second one, the density for one of contacting materials  $\rho_1$  is essentially less than density of another material, i.e.  $\rho_1 \ll \rho_2$ . In practice, such conditions are implemented on the boundary of solid/liquid materials with air.

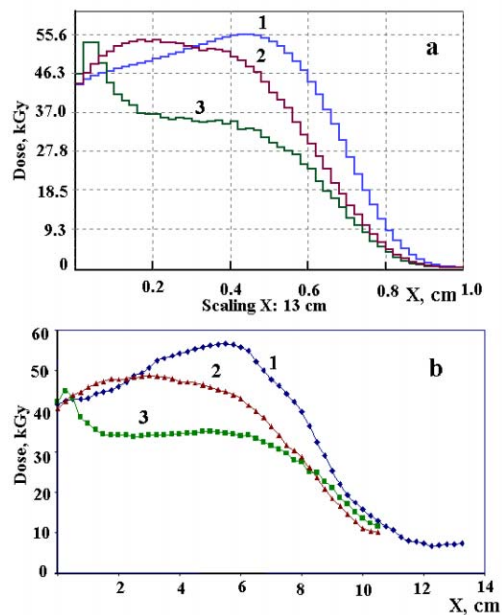
Heterogeneous target from three contacting materials two wooden and one Al blocks was placed in the center of

a standard Al box with the size of 560x480x200mm and walls thickness of 1 mm. Such boxes usually use in practice for sterilization of medical devices. Additional two wooden blocks were close contacted with walls of Al box. There are six boundaries where dosimetric films were inserted: wood - wood (1), wood - air (2), wood-Al(3), Al-air(4), wood - middle of front wall of Al box (5), wood - middle of side wall of Al box (6).

Cellulose Triacetate (CTA) dosimetric film (FTR-125) with thickness 0.125 mm and density 1.32 g/cm<sup>3</sup> was used for measurement of a depth-dose distribution. Three dosimetric films were inserted between contacting blocks and wooden block with walls of Al box in parallel with axis of EB. On the boundary of wood - air and Al-air, three dosimetric films were close placed side-by-side on the lateral surface of wooden and Al blocks in parallel with EB axis.

The heterogeneous materials were irradiated by a scanned electron beam with energy 10 MeV, average beam current 0.34 mA, scan width 46 cm, conveyer speed 0.128 m/min, angular spread 3 degree.

Figs.1(a) and (b) represent the results of Monte Carlo simulation (a) and experimental measurements (b) of the depth-dose distribution on the boundary of wooden blocks with walls of Al box irradiated by scanning EB. Curve 1 is the depth-dose distribution in homogeneous wooden material. Curve 2 is the depth-dose distribution in the wooden block on the boundary with the middle of front wall of Al box, curve 3 - on the boundary of wooden block with the middle of side wall of Al box.



Figures 1(a) and (b). The depth-dose distributions on the boundary of wooden blocks with walls of Al box. (a) Simulation results. (b) Experimental results.

Al box for movement of materials through the field of EB irradiation have two different boundaries with respect to formation of an absorbed dose in an irradiated material,

which contacts with box walls. The first type of boundary is located in plane XY of scan EB on the front walls of the box relatively direction of conveyer motion, the second one is located in plane XZ on the side walls.

The difference of the shapes for depth-dose distribution (see Figs. 1(a) and (b)) on the boundaries 5 and 6 is determined by difference of the angle of incidence for EB on the boundaries in plane XY of EB scanning. On the boundary 6, EB irradiation of the wooden block contacting with middle of side wall of Al box is performed at angle 10 degree in respect to EB axis in plane of scan XY, on the boundary 5 - at angle - 0 degree.

The analysis of the depth-dose distribution on the Figs. 1(a) and (b) demonstrate a good agreement of the shapes of depth-dose distributions for theoretical predictions and experimental validation and a satisfactory agreement in absolute values. Greater value of the experimental absorbed dose at the end of electron range in wooden material in comparison with simulation results is determined by influence of back scattered electrons from materials of conveyer platform.

Results of Monte Carlo simulation curves 1 and 2 and experimental results curves 3 and 4 of the depth-dose distribution near the boundary of Al block with air are presented in Fig.2. Curves 1 and 3 are the depth-dose distributions in center and curves 2 and 4 - near the boundary of Al block with air. Experimental results for dose distribution were measured by CTA dosimetric film placed on the lateral face of Al block. The same results were received on the boundary of wooden blocks with air.

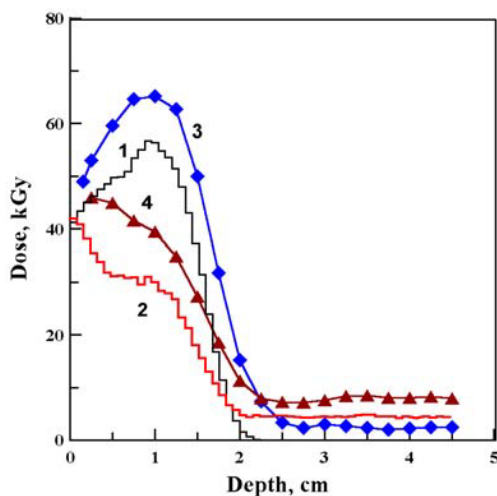


Figure 2. Simulation and experimental results of the depth-dose distribution near the boundary of Al block with air.

The visual analysis of the depth-dose distribution near the boundaries Al-air and wood-air demonstrates a satisfactory agreement of the shapes and absolute values of the depth-dose distributions near the boundaries of Al and wooden blocks with air for theoretical predictions and comparisons with dosimetry.

For more correct comparison of theoretical predictions with dosimetry for boundaries effects of dose distributions of contacting materials with essentially different densities, it is necessary to have more detailed and accurate information about radiation facility setup, parameters of electron beam, spatial orientation of irradiated target with respect to electron beam axis.

The ModeRTL program allows to determine not only optimum parameters of a mode of an irradiation or to determine optimum setup of dosimetric experiment, but also to determine possible errors for dose distribution, which arise because of uncertainties of various parameters in actual experiment. The program allows to forecast and to calculate necessary accuracy, which it is necessary to set for the good agreement of simulation results and experimental data.

## CONCLUSION

Theoretical investigations of boundaries effects of dose distribution at passage of electron irradiation through heterogeneous targets were performed on base of mathematical modeling by ModeRTL software. Basic regularities of an electron dose distribution near the boundaries of the contacting materials with different density and/or atomic number were predicted by computer simulation. The experimental and theoretical examinations of boundary anomalies of the absorbed dose distribution were carried out on model samples. Both used materials (Al, PE, wood, CTA film) and radiation facility on the basis of the LAE 13/9 are typical for a series of radiation technologies. An experimental validation of basic regularities of boundary effects with dosimetry was confirmed.

It was established, that the boundary anomalies of a dose are always realized at radiation processing of heterogeneous materials in practice. Investigation of those anomalies is necessary to determine the location zones and value of maximum and minimum absorbed doses in an irradiated product, to estimate the quality and mass throughput rate of an irradiation process fulfilled on radiation facility. It is shown that an application of designed ModeRTL software for planning of irradiation on RTL, control and execution of irradiation process, and interpretation of dosimetric results is correct and useful in practical activity.

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