APPLICATION OF PENELOPE SYSTEM TO SUPPORT THE RADIATION TECHNOLOGIES BASED ON LU-10 LINAC

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A new code based on the PENELOPE system has been worked out for simulation and optimization of product processing modes on LU-10 technological accelerator (8...18 MeV, 12 kW) with scanned electron beam. The results of simulation of 3D absorbed dose distributions in objects of rectangular shape and similar to real plant geometry and irradiation parameters are presented. Influence of object size, its composition and density, walls, energy spectrum of the beam and other factors are studied. The causes of the dose distribution irregularity as well as the methods of its decreasing are discussed.

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1. INTRODUCTION

Growing demands for a higher quality of radiation processing of products [1] forces to investigate in more detail the factors affecting the results of radiation. In particular case, the absorbed dose (AD) distribution uniformity in the object volume depends on electron energy spread, air, dimensions, compound and density of object. In the present paper the results of investigation by the simulation method, the influence of these factors on AD distributions in objects irradiated at the technological accelerator LU-10 [2] are described.

The calculations were performed for three materials: cellulose of 0.1939 g/cm^3 average density over box volume, rubber grit of 0.4 g/cm^3 density, polyethylene of 0.94 g/cm^3 density. It was assumed that the irradiated material has a homogeneous structure and rectangular form. Under these conditions the absorbed radiation energy distribution dependencies on high, width (transverse distributions) and depth (longitudinal distribution) within an object have been investigated. The quality degree of the AD distribution was estimated with a non-uniformity coefficient:

$$NUD=(Dmax-Dmin)/(Dmax+Dmin), \qquad (1)$$

where *Dmax*, *Dmin* are the maximum and minimum values of AD within object.

The simulation is based on the PENELOPE code system [3] added with set of original programs applied to the specific circumstances of the LU-10.

2. DISCRIPTION OF LU-10

LU-10 is the one section electron line accelerator equipped with a scanner system spreading beam electrons in the vertical plane XOZ [2]. Horizontal Z-axis is directed along the electron movement. The XOY coordinate plane coincides with the foil front surface of the exit window. Y-axis is directed along the conveyer movement. Real linac parameters, used for simulation, are described in paper [2].

Beam electron characteristics (energy spectrum, radial and angular distributions) beyond the foil, in air, at front wall of the object are shown in Fig.1-2.

In Fig.1 the spectrum, simulated by special code, is shown in comparison with experimental spectrum values. In the same figure the electron spectrum of the irradiated object is presented.

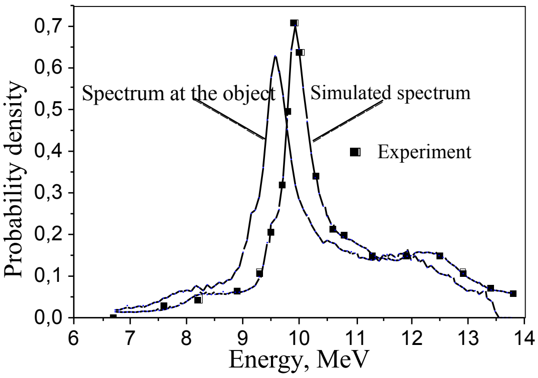

Fig.1. LU-10 electron spectrums

Average spectrum energy is equal to 11.5 MeV, i.e. higher than its value of 10 MeV at maximum. After passing the exit window foil and air the spectrum has a maximum at energy of 9.6 MeV. The beam electrons produce a circular cone of scattering with its apex at the first foil wall. At the front object wall 99% of beam electrons are within cone of 18 cm radius and have the angle straggling up to 20 degrees.

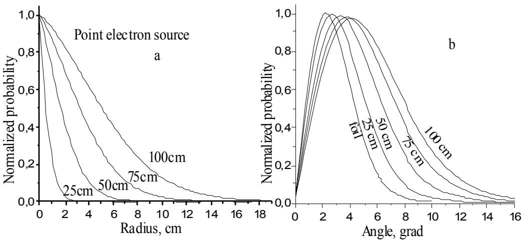

Fig.2. Radial and angular distributions of beam electrons after passing of 50μm Ti foil and 25; 50; 75; 100 cm air

3. DOSE DISTRIBUTION SHAPING

3.1. The mechanism of shaping of local (point) dose is important to believe of origination of non-uniform dose distribution in the object on whole. In Fig.3 the AD distributions in cellulose (curves 1), rubber (curves 2) and polyethylene (curves 3) from the 10MeV electron point source are demonstrated. The dash line corresponds to particles flying from the source to the object in vacuum, the solid line is the same for the particles passing the foil and air.

The AD depth distribution shapes from electrons passing vacuum are defined by the stopping power and scattering material possibilities (Fig.3,a dash lines). Less AD region size from electrons passed foil and air are because of inessential electrons energy losses in air.

Radial absorbed energy region sizes for electrons passed vacuum are defined only by possibilities of scattering material (Fig. 3,b dash lines).

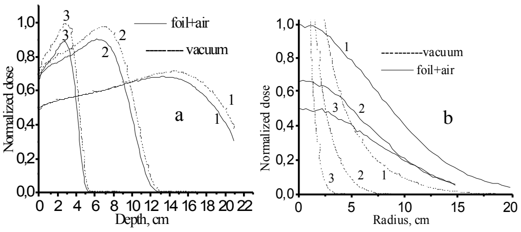

Fig.3. AD distributions on depth and radius

The region sizes depend on materials and may be from several centimeters up to 10…15 cm. For the points near the object surface, the absence of material in the corresponding transverse direction reduces AD. In corner points the reduction is more appreciable, because the material reflecting electrons is absent in three directions.

The presence of air makes the radiated surface larger and the AD distribution is more uniform. (Fig.3, solid lines). So the transverse AD region size becomes more increased.

3.2. **Dependence of dose distribution on depth** is shown in Fig.4. In this case rubber was irradiated at the same exposition by 10 MeV energy electrons. In Fig.4 the AD distributions for two box depth sizes: 16 cm (curves 1) and 20 cm (curves 2) are demonstrated.

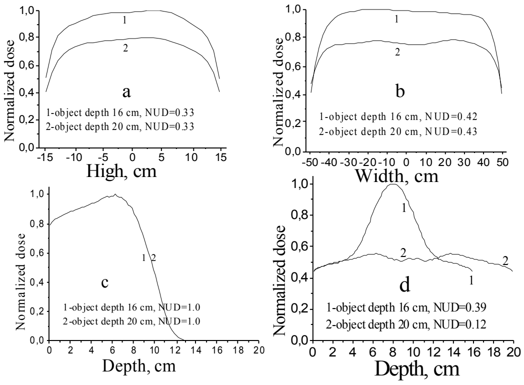

Fig.4. AD distributions in rubber

The one-side depth dose distributions in both cases are the same (Fig. 4,c). The NUD derived by two-side irradiation against the height and width are practically not changed (Fig. 4,a-b). The reductions of dose at side surfaces are seen well. In the middle of the object of 16 cm depth there is a wide maximum of dose and relatively high NUD=0.39 (Fig.4,d). However, if the depth to be increased reaches up to 20 cm, the value of NUD=0.12 become satisfactory.

3.3. Since the average spectrum electron energy is 1.5 MeV more than its value at spectrum maximum, **the real spectrum dose distribution** is greater a little then that value for the 10 MeV monoenergetic electron beam. Particularly, the AD distribution curve 2 in Fig.4,d against depth has again maximum and NDU becomes 0.15. However, if the object depth is extended from 20 to 21 cm, the NUD decreases up to 0.09.

3.4. We made **calculations to affect the box walls on dose distributions in cellulose.** Generally, the products come in processing in goffered cardboard boxes of 0.14 g/cm^3 density. Four-side box walls are 3 mm thick and two wall-lids of 5 mm thick. For the object without walls the NUD=0.15, 0.20 against width and height, respectively, and NUD=0.15, 0.16 for object with walls. Effect is considerable, when the thickness of sidewalls is increased up to 5 cm. In this case the abrupt dose decrease regions near the walls become considerably smaller and dose non-uniformity become NUD=0.04, 0.06. In these cases the walls are material continuation of product and as a result the dose becomes more flattened.

We calculated AD inclusive of aluminum tare walls of 1.5 mm thick. Coefficients NUD=0.16, 0.19 are practically the same values as in the case for cellulose walls. The integrated AD within the object in this case is little less because an inconsiderable part of energy loses in front aluminum tare wall.

3.5. The air plays important role, because it creates the primordial radiation anisotropy of field on the object, necessary for uniform irradiation of the object.

We are investigated **the influence of X-, Y-side air layers** on uniformity dose distributions. The results are shown in Fig.5. The rubber was irradiated when the beam exposition is the same.

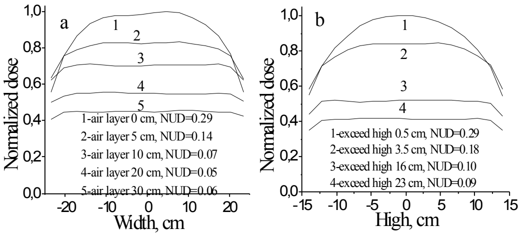

Fig.5. The influence of Y-side air layers (a) and the scanner amplitude (b) on the absorbed dose distribution in rubber

In Fig. 5,a the influence of nearest Y-side air layers on NUD is presented. For this aim the bounded scanner work time was simulated. Curves 1 (layer is 0 cm) corresponds to the case when the scanner works only during the object crosses the scan-plane. Curves 2 (layer is 5 cm) correspond to the case when the scanner starts to work, when the distance between the scan-plane and approaching object surface is 5 cm, and finishes to work when the object passes the scan-plane and is 5 cm removed from the scan-plane, and so on. The results show, that theY-side air layers do not practically affected on dose distributions against heights, but appreciably improve the uniformity against width, decreasing NUD from 0.29 to 0.05. The air layers, which are removed more then 20 cm, do not practically improve NUD.

In Fig. 5,b **the influence of upper and lower air layers** on NUD is shown. For this aim the scanner amplitude was changed. Curves 1 corresponds to the case when the deviation of the beam axis on the front object wall exceeds the object height more than by 0.5 cm above and below. Curves 2 correspond to the case when the spread of beam axis exceeds the object heights more than by 3.5 cm above and below, and so on. The calculations show, that vertical air layers do not practically affect on dose distributions against width, but appreciably improve the uniformity against height, decreasing NUD from 0.29 to 0.09. The air layers, which are higher more then 23 cm, do not practically improve NUD.

3.6. The technological screen is the aluminium sheet placed before the object to be irradiated. It was used as means of formation of the uniformity dose distribution against depth. In our calculations the thickness of screen was enlarged up to 8 mm under unchanged exposition. The non-uniformity of the dose distribution against height and width did not practically vary. At the same time the NUD against depth is appreciably decreased from 0.14 to 0.02.

5. CONCLUSIONS

1. When two-side irradiation occurs the electron energy spreading decreases the absorbed dose non-uniformity against depth.

2. Tare walls of cardboard or aluminium up to 1.5 mm thick do not appreciably influence on the uniformity of absorbed dose distribution.

3. The air layer surrounding an object plays an important role for shaping of transverse dose distributions. The thickness of layer is approximately equal t the scattering cone radius at the object place. Thus the optimal distances between the objects on the conveyer and the scanner amplitude are determined.

4. The more uniform dose distribution against thedepth may be obtained by several ways:

- Changing of electron energy,
- Making of special tare boxes with metal walls,
- Using the technological screens.

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ПРИМЕНЕНИЕ ПРОГРАММНОЙ СИСТЕМЫ PENELOPE ДЛЯ СОПРОВОЖДЕНИЯ РАДИАЦИОННО-ТЕХНОЛОГИЧЕСКИХ ПРОЦЕССОВ НА УСКОРИТЕЛЕ ЛУ-10

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Для моделирования и оптимизации режимов обработки продукции на технологическом ускорителе ЛУ-10 (8...18 МэВ, 12 кВт) со сканируемым пучком электронов разработан пакет на основе программной системы PENELOPE. Приведены результаты моделирования 3D распределений поглощенной дозы в объектах прямоугольной формы при близких к реальным геометрии установки и условиям облучения. Рассматривается влияние на получаемые распределения размеров объекта, его состава и плотности, стенок, энергетического разброса электронов, а также других факторов. Исследуются причины неравномерности распределения поглощенной дозы и пути ее снижения.

ЗАСТОСУВАННЯ ПРОГРАМНОЇ СИСТЕМИ PENELOPE ДЛЯ СУПРОВОДЖЕННЯ РАДІАЦІЙНО-ТЕХНОЛОГІЧНИХ ПРОЦЕСІВ НА ПРИСКОРЮВАЧІ ЛП-10

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Для моделювання й оптимізації режимів опрацювання продукції на технологічному прискорювачі ЛУ-10 (8...18 МеВ, 12 кВт) пучком електронів, який сканується, розроблено пакет на основі програмної системи PENELOPE. Наведено результати моделювання 3D розподілів поглиненої дози в об'єктах прямокутної форми при близьких до реальних геометрії установки й умовам опромінення. Розглядається вплив на отримані розподіли розмірів об'єкта, його складу і щільності, стінок, енергетичного розкиду електронів, а також інших факторів. Досліджуються причини нерівномірності розподілу поглиненої дози і способів її зниження.