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IRRADIATION DOSE UNIFORMITY IN TREATMENT OF SPHERICAL OBJECTS WITH ACCELERATED ELECTRONS

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Abstract. *The study confirms the impact of aluminum plates added in 5-10 MeV electron irradiation method on dose uniformity of a spherical object. It was found that the maximum dose uniformity throughout a spherical volume can be achieved in computer simulation by varying the initial electron energy from 5 to 10 MeV and modifying the thickness of aluminum plate from 3 to 5 mm.*

Keywords: *irradiation treatment, absorbed dose uniformity, accelerated electrons, aluminum plates*

1. INTRODUCTION

These days radiation technologies are applied in a wide range of areas, including irradiation therapy and medical diagnostics, sterilization in transplantology and pharmaceutical industry, as well as irradiation treatment of chemical substances and foods.

It's a common trend to use electron accelerators for irradiation of organic and non-organic objects [1] since the dose range absorbed by the irradiated object and the processing rate during electron irradiation are higher to compare with radioactive sources, such as ^{60}Co and ^{137}Cs [2]. However, it may be difficult to ensure dose uniformity in objects thicker than 4 cm as a result of a low depth of penetration in irradiation with the electron energy lower than 10 MeV.

Dose uniformity is the ratio between the minimum and maximum values of absorbed dose throughout the irradiated volume. While the majority of medical tools require the dose uniformity of around 0.5, foodstuffs, including chilled and processed meat and fish, fruits and vegetables, call for a higher dose uniformity of at least 0.8 [3] - [6].

Nonuniformity of the absorbed by the object dose distribution can be caused by nonlinear electron dose distribution or uneven distribution of objects in the package, complex geometry as well as structure, chemical composition and density of irradiated objects.

It is possible to increase the uniformity of the dose distribution by treating the objects with electrons of different energy in several irradiation sessions [7]. However, repeated irradiation increases the time of treatment, which is undesirable for the objects that have to be stored in cooling chambers. Therefore, it is important to develop a method which would allow to increase the uniformity of the dose distribution in irradiated objects of complex geometry in one irradiation session.

The study focuses on a method for increasing dose uniformity in spherical objects using aluminum plates during electron irradiation treatment.

2. MATERIALS AND METHODS

The simulation method used in the study provided for bilateral irradiation of spherical water phantom with the diameter of 4.6 cm and the density of 1 g/cm3 with the toolkit Geant4. The phantom was irradiated with 5 – 10 MeV electrons. The electron source was a 5 cm square located 2.5 cm away from the phantom.

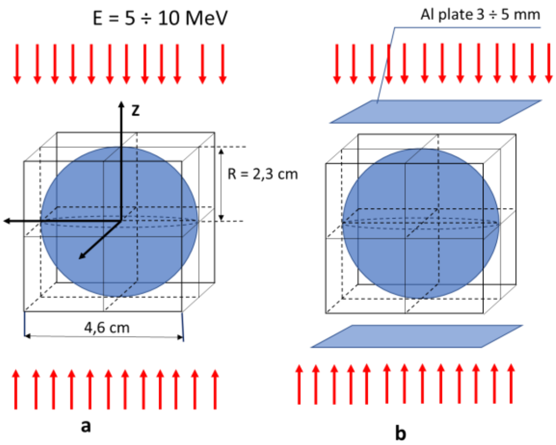

Figure 1. The bilateral irradiation method involving simulation of 4.6 cm diameter spherical water phantom, irradiated with electrons, with aluminum plates on both sides of the phantom

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Figure 1 shows the electron irradiation method with 3-5 mm thick aluminum plates and without them. The initial direction of electron flow was parallel to OZ axis of coordinate system in the center of the sphere.

Computer simulation involved a cube with the edge of 4.6 cm which was split into 40 x 40 x 40 cells and had the same center as the spherical water phantom (Fig. 1). Each *i* cell was estimated as a sum of energies E_i absorbed in *i* cell as a result of the electron interaction with the matter contained in the i cell to determine the absorbed dose distribution in the water phantom. The simulation also determined E^2_i values and the number of interactions N_i in *i* cell.

The simulation allowed to estimate the dose absorbed by each cell and standard deviation to assess absorbed dose error:

$$D_i = \frac{\sum_{j=1}^{N_i} E_{ij}}{m_i} \quad (1)$$

$$S_i = \sqrt{\left(\frac{1}{N_i - 1}\sum \frac{N_i}{j=1} E_{ij}^2 - \left(\frac{1}{N_i - 1}\sum_{j=1}^{N_i} E_{ij}\right)^2\right)} \quad (2)$$

where $\sum_{j=1}^{N_i} E_{ij}$ is the sum of energies lost in i cell, Ni is the number of events in i cell, and mi is the mass of i cell, $\sum_{j=1}^{N_i} E^2{}_{ij}$ is the sum of E^2_i values in *i* cell.

The uniformity of dose distribution in the water phantom irradiated with electrons was estimated as $K = \frac{D_{\min}}{D_{\max}}$ where D_{min} and D_{max} are the minimum and the maximum dose values observed in the water phantom. The surface cells which were partly filled with water were not taken into account.

The irradiation uniformity coefficient (was compared for different scenarios with and without 3, 4 and 5 mm thick aluminum plate for 5 - 10 MeV electron energy.

3. Results and discussion

Table 1. K values for different irradiation configurations.

Irradiation configuration	Without a plate	3mm thick plate	4mm thick plate	5mm thick plate
5 MeV	0.335	0.016	0.001	0.001
6 MeV	0.324	0.658	0.288	0.047
7 MeV	0.358	0.541	0.704	0.714
8 MeV	0.433	0.499	0.560	0.633
9 MeV	0.561	0.564	0.558	0.567
10 MeV	0.641	0.649	0.641	0.624

As it can be seen from Table 1, increasing electron energy from 5 to 10 MeV causes the dose uniformity in the water phantom to rise from 0.335 to 0.641. The standard deviation of K did not exceed 0.5% from each value.

Including an aluminum plate in 5-10 MeV electron irradiation significantly increased the uniformity coefficient (K). For the electron energy 5 MeV the coefficient (K) decreased with the increase in plate thickness. Including a 3 mm aluminum plate in 6 MeV electron irradiation raised K value to 0.658, which is 2 times higher than irradiation without a plate. When an aluminum plate was integrated in the irradiation with 7 MeV and 8 MeV electrons, the coefficient (K) went up with the increase in plate thickness ranging from 3 mm to 5 mm. For the electron energy 9 MeV the maximum value of K = 0.567 was registered when a 5 mm aluminum plate was added, while the addition of a 3 mm plate during 10 MeV electron irradiation brought the coefficient (K) up to 0.649.

Overall, adding a 5 mm aluminum plate in 7 MeV irradiation raised K value to 0.714, which is the maximum uniformity achieved for 5-10 MeV electron irradiation of spherical water phantom with the diameter of 4.6 cm.

Including aluminum plates in the electron irradiation method modifies the initial monoenergetic spectrum towards lower electron energies, shortening their path in the water phantom, which causes the absolute value of the minimum absorbed dose to decrease. The coefficient (*K'*) was introduced to assess the impact of the added aluminum plate on the minimum absorbed dose as $K' = \frac{D_{\min}^{plate}}{D_{\min}}$, where $D_{\min}^{plate}$ is the minimum absorbed dose with a plate of different thickness, D_{min} is the minimum absorbed dose without a plate.

Table 2 shows the coefficient (*K'*) for different configurations with and without 3, 4 and 5 mm thick aluminum plate for 5 - 10 MeV electron energy.

Table 2. K' values for different irradiation configurations.

Electrons energy, MeV	3mm thick plate	4mm thick plate	5mm thick plate
5 MeV	0.029	0.002	0.002
6 MeV	1.265	0.490	0.081
7 MeV	1.225	1.313	1.123
8 MeV	1.011	1.081	1.101
9 MeV	0.948	0.915	0.896
10 MeV	0.974	0.948	0.905

As it can be seen from Table 2, adding aluminum plates in 6-8 MeV irradiation increased the absolute minimum absorbed dose by 8.1 – 31.3% while for the electron energy 9 MeV and 10 MeV the absolute minimum absorbed dose decreased by 2.6% and 10.4% respectively.

Thus, a 5 mm aluminum plate added in 7 MeV electron irradiation of spherical water phantom with the diameter of 4.6 cm increased the dose uniformity up to 71.4% which could not be achieved for irradiation without plates. At the same time, adding the plate decreased the absolute minimum absorbed dose by 10%.

4. Conclusion

Adding aluminum plates in electron irradiation method allow to increase the dose uniformity of a spherical object. It is possible to achieve the maximum dose uniformity throughout a spherical object by varying the initial electron energy and the thickness of aluminum plate in simulation.

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