DOSE ADJUSTMENT TO ENSURE UNIFORMITY OF CYLINDRICAL FOODSTUFF IRRADIATION

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Abstract. This study focuses on achieving a higher uniformity of 10 MeV electron treatment of cylindrical products by including aluminum modifiers of different thicknesses in the irradiation scheme. It was simulated the irradiation of cylindrical water phantom by beams of accelerated electrons with an energy of 10 MeV from two opposite sides using GEANT 4. During the simulation, aluminum plates-modifiers of different thicknesses of 1, 1.5 and 2 mm were added between the cylindrical phantom and the beam output in order to assess dose uniformity inside the phantom. It was found that the higher the thickness of aluminum plates, the more uniformity could be achieved. While 1 mm and 1.5 mm plates enable the efficiency ratio of 30 % and 45 %, respectively, a 2 mm modifier increases the uniformity of irradiation up to 60 %. In this way, computer modeling proves that inserting beam plates-modifiers between irradiated samples and beam output for irradiation from two opposite sides allows to considerably increase the uniformity of sample irradiation with complex geometry.

Keywords: Foodstuff irradiation, dose distribution, uniformity irradiation, beam modifiers

1. INTRODUCTION

Food safety is a major concern these days with the increase in a number of consumers across the world and frequent cases of food poisoning as a result of improper handling of products. The modern trend of convenience food calls for treatment methods that would ensure human health and environmental safety while extending the shelf life of processed and pre-packaged foods [1-3].

While irradiation processing has proved to be the most efficient method that allows to achieve the desired properties of foodstuff for long-term storage, now the researchers are refining the irradiation parameters to achieve a uniform and stable result which can be replicated on a wider variety of products. The application of cutting-edge accelerators and new simulation methods has turned into reality irradiation treatment of foods with complex geometry.

It has been established by the World Health Organization that foods irradiated with the doses of up to 10 kGy are suitable for consumption [4]. While the doses specified in the international regulations cover all types of foodstuffs, some adjustments are required for certain categories of products to achieve the desired result. The acceptable dose range varies from product to product [1-7]. It is just as important not to go below the lower limit as not to exceed the upper limit. If the dose is lower than acceptable, it will not inhibit the growth of pathogens for the extended period of time, while exceeding the upper limit will cause undesirable changes in the properties of treated product [8-15].

Since both food industry and radiation treatment centers seek to increase the volume of irradiated products, the use of electron accelerators in industrial treatment of foodstuff is becoming a common trend [16-19].

At the same time, food radiation focuses on achieving greater uniformity of exposure, which represents a challenge for researchers, who are faced with the need to align the performance of the accelerator to meet the requirements of the diverse market of foods ranging in geometry and texture. Another factor which makes it difficult to ensure irradiation uniformity throughout the product is the layout of items in the package. While it is easy to achieve uniform irradiation of loose products, such as flour or spices, food items of varied texture put together in one package require a much more stringent control of dose exposure within a specified narrow range. Moreover, nonlinear character of the dose distribution curve throughout the product due to a small value of effective electron pass makes it increasingly difficult to achieve irradiation uniformity. This is the case with foods of complex geometry, such as cylindrical or spherical items. Such limitations cause food manufacturers to refrain from irradiating a range
of foodstuff for fear of failure to preserve the original properties of products.

To expand the range of foodstuffs which can be successfully irradiated for a longer shelf life, it is suggested to place beam modifiers of different configuration between the beam output and the product to adjust the electron spectrum and thereby achieve the dose uniformity throughout the product. Beam modifiers are implements that consist of one or several plates made of different materials and their configuration is determined by a computer simulation taking into account physical and technical properties of beam sources as well as characteristics of the product. Electrons with the energy of up to 10 MeV incur ionization losses which alter the initial electron spectrum, causing dose distribution throughout the product to change, as well.

These days, there is an increasing demand in irradiation treatment of processed foods such as sausages, ham, different canned foods and preserves in a cylindrical package. This package shape prevents the substance from uniform irradiation during the conventional treatment. The absorbed dose in the cross section may vary 5 times depending on the value of beam energy, irradiation method as well as the diameter of the cylindrical product.

The acceptable dose range for irradiation treatment of meat and fish products is from 1 kGy to 2 kGy depending on the type of product, and the difference in dose values in cross sections should not be more than 2 times [14]. It is suggested to place aluminum plates of different thickness between the beam output and the cylindrical product to achieve a higher uniformity of irradiation treatment.

The purpose of the study is to achieve a higher uniformity of electron treatment of cylindrical products in simulation by including aluminum modifiers of different thicknesses in the irradiation scheme.

2. MATERIALS AND METHODS

For the purpose of the experiment, we used a 10 MeV industrial electron accelerator with a scanning beam and the average power of 15 kW which was installed at the Russian Irradiation Center Tлечеor. Electron energy varies from 5 MeV to 9.5 MeV. A high frequency of scanning ensures the uniformity of beam distribution across the scanned area [20].

The parameters of the beam modifier as well as dose distribution values were calculated using a computer simulation based on the Monte-Carlo method. Source code GEANT 4 used in experiments was developed in CERN especially for simulation of physical processes behind irradiation [21-22].

The scanning beam was simulated as the 8 cm x 12 cm rectangular beam. We used a cylindrical phantom, with the diameter of 7.5 cm and the length of 11 cm, consisting of the muscle tissue with the density of 0.95 g/cm³ whose properties were established as per NIST “G4_MUSCLE_STRIATED_ICRU” database.

During the simulation, \(2 \times 10^9\) electrons, with the spectrum corresponding to that of the industrial accelerator, irradiated the phantom from two opposite sides along the X axis (Figure 1).

Cylindrical objects with the diameter exceeding 6 cm should be irradiated from two opposite sides with the maximum effective energy since the effective pass of 10 MeV electrons is less or equal to 6 cm and the density and the composition of the muscle tissue and water are practically the same.

![Figure 1. Irradiation treatment of cylindrical products](image)

**3. RESULTS**

Figure 2 shows the relative dose distribution in the cross section of the cylindrical phantom with the coordinates: \(5 \text{ mm} < X < 75 \text{ mm}, 5 \text{ mm} < Y < 75 \text{ mm}, Z = 1 \text{ mm}\). \(D_{\text{min}}/D_{\text{max}}\) is the ratio of the minimum dose value to the maximum dose value in the cross-section of a cylindrical phantom.

![Figure 2. Relative dose distribution in the cross section of a cylindrical phantom](image)
As it can be seen, cross sections with the coordinates $30 \text{ mm} < X < 50 \text{ mm}$, $5 \text{ mm} < Y < 30 \text{ mm}$ and $50 \text{ mm} < Y < 75 \text{ mm}$; $0 \text{ mm} < Z < 110 \text{ mm}$ were overexposed compared to other cross sections. A two-side direct treatment of the phantom fails to enable the required uniformity of irradiation, with the efficiency ratio not higher than 25%.

A much higher uniformity was achieved using aluminum plates of different thickness placed between the cylindrical phantom and the beam output.

Figure 3 (a,b,c) shows relative dose distributions in the cross section of the phantom with the coordinates: $5 \text{ mm} < X < 75 \text{ mm}$, $5 \text{ mm} < Y < 75 \text{ mm}$, $Z = 1 \text{ mm}$ using Al modifiers with the thickness of 1 mm, 1.5 mm and 2 mm.

As it can be seen, the higher the thickness of Al plates, the more uniformity can be achieved. While 1 mm and 1.5 mm plates enable the efficiency ratio of 30% and 45%, respectively, a 2 mm modifier increases the uniformity of irradiation up to 60%.

4. Conclusion

Computer modeling proves that inserting beam modifiers between irradiated samples and beam output for irradiation from two opposite sides allows to considerably increase the uniformity of sample irradiation with complex geometry. Thus, using a 2 mm Al plate during the irradiation of a cylindrical phantom of 7.5 cm in diameter increases the dose efficiency ratio up to 60% compared with the direct treatment, which ensures the ratio of around 25%.

This approach, based on the Monte-Carlo method, allows to determine the optimal geometry of modifiers to achieve the required dose uniformity in the product of any configuration and composition. The algorithm used takes into account physical and technical characteristics of irradiation sources and treated products.

Currently, the study is purely analytical and we have prepared a set of modifiers which are going to be used in the treatment of cylindrical objects of different diameter and composition in industrial conditions.

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