PROVISION OF DOSE HOMOGENEITY IN EXPERIMENTS FOR DEVELOPING METHODS OF FOOD IRRADIATION

P. A. Bystrov, IPCE RAS, 199071 Moscow, Russia
V. P. Filippovich, [142703] Vidnoe, Moscow region, Russia
A. V. Prokopenko, MEPhI, 115409 Moscow, Russia
N. E. Rozanov, S. N. Puchkov, MRTI RAS, 117519 Moscow, Russia

Abstract

At present, interest is growing in the use of an electron beam irradiation for preserving food. Presented the study of using electron beam irradiation on food products, having a density, comparable to the density of water. The study uses computer code "BEAM SCANNING" for calculation the dose distribution in products. One-sided and two-sided irradiation of objects under different ways of laying is considered.

INTRODUCTION

At present, there is a significant increase in interest in technology of radiation food processing in Russia. This is due to beginning of the normative documents development in 2014 for use of radiation technologies in agriculture and food industry [1]. In April 2015, a fundamental document was published - State Standard ISO 14470-2014 [2].

The development of irradiation technologies led to increase in number of irradiation centers, based on electron beam accelerators. In comparison with both conventional canning methods and γ-irradiation, the electron beam irradiation technology is most effective and safe. It allows replacing or dramatically reducing the use of food preservatives, fumigants and other chemicals [1]. When irradiating products with an electron beam, it is easy to control the average absorbed dose; the products are disinfected in a sealed package, which is the advantage of the method.

Using an electron beam to irradiate products, one should be very careful, since food products have strict limitations on the minimum and maximum allowable dose. Inhomogeneous irradiation can lead to low efficiency of the process if some product areas are less irradiated, or deterioration of the quality in case of local overexposure. This entails the most stringent requirements for the development and verification of irradiation techniques.

This technology has long been applied to the disinfection of dry products having a low density. When processing objects, having a density comparable to that of water, an inhomogeneous radiation dose profile may arise due to the insufficient penetrating power of the electron beam. This problem makes impossible irradiating of large nomenclature of products. In experimental work this problem can lead to errors when performing studies on irradiation.

Another problem with electron beam technology is the possible reduction of radiation dose in separately irradiated small objects which have sizes, comparable to depth of beam penetration. In this case the effectiveness of irradiation can be dramatically decreased.

When irradiating objects, which have characteristic sizes of less than 5 centimeters, density greater than that of water with electron beam of electron energy less than 10 MeV, one can't be sure of the uniformity of the dose distribution. The dose profile in this case can hardly be predicted.

In order to find the distribution profile of doses in the objects of the study, the irradiation process is simulated using a specially modified computer code "BEAM SCANNING" [3-7]. Special modification made possible the calculation of dose profiles in the objects having more complicated shapes rather than a box.

MATERIALS AND METHODS

This installation "Raduga", presented on Fig. 1 is based on a linear accelerator. The characteristic parameters of the accelerated beam: average energy is about 5 MeV, pulse beam current is up to 250 mA, pulse duration is 4-6 μs, repetition frequency is 300 Hz, average beam power is 1.5-1.7 kW. The installation is provided with local radiation shielding and automated conveyer.

Figure 1: Radiation installation "Raduga".

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ISBN 978-3-95450-197-7

Accelerated electron beam enters the beam scanning system where it is being deflected to cover the full surface of the irradiated objects, travelling on conveyer. In this case, the axis of the accelerator (Z axis), the direction of the beam scan (axis X), and the direction of motion of the objects (the Y axis) are mutually perpendicular.

In the experiments, the products were irradiated - packages with tomatoes located in one layer and dry beans (Fig. 2). Packages were exposed to bilateral irradiation with doses from 0.29 to 10 kGy. The absorbed dose in each of experimental series was monitored by a film dosimeter that was openly located on the wall of the package. In experiments the irradiation of products was performed with different average doses.

Figure 2: Tomato layout.

Irradiation dose distribution was obtained by numerical simulation of the experiments. Calculations were carried out using the computer program "BEAM SCANNING", which was specially modified to calculate doses in objects of complex shape. The form of objects in the program is determined by defining the three-dimensional grid density distribution function in a rectangular volume, which corresponds to a box filled with dense objects and separating filler of minimum density of the characteristic biological material. The object is specified as the combination of primitive forms - a cone, a cylinder, a box and a sphere, which is enough for modeling typical forms of objects, used in experiments.

As a result of the calculations, the program displays a three-dimensional distribution of the radiation dose, and the dose distribution in the given sections. The absolute value of the dose at any point of the object can be obtained from its relative distribution, using the ratio in which the relative calculated dose at place of the dosimeter corresponds to the absolute dose measured by it. The study of the three-dimensional distribution of the relative dose obtained using the "BEAM SCANNING" program allows one to evaluate the effectiveness of the irradiation technique.

RESULTS OF THE STUDIES

From preliminary calculations one should state that there is a significant dependence of dose profile from the transverse dimensions of the irradiated object. Dose decrease takes place in objects which transverse dimensions (in a plane perpendicular to the beam) are less than the penetration depth of the beam into the irradiated substance. Consider the dose distribution from depth in cube with an edge of 30 cm. and in the object which has dimensions of 4x4 cm wide, same height. Objects are irradiated with a wide beam, as shown on Fig. 3.

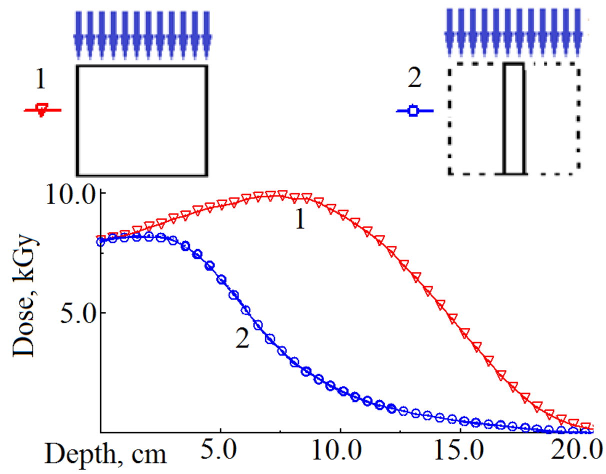

Figure 3: Dose drop in small objects.

Figure 3 shows the dose profiles calculated by the "BEAM SCANNING" program, depending on the depth along central line for these cases. The radiation dose curve along the central axis of the small object is much lower than in the cube (up to 4 times at maximum of first curve). This result is understandable if we assume that in the irradiation of each of the parts of a large object, electrons coming from the neighboring parts of it participate. So the maximum filling of the irradiated space increases the radiation dose and its homogeneity.

Consider the results of simulation of one-side and two-side irradiation of tomatoes - the spherical objects with a diameter of 6 cm, located separately and side by side, having density of water. Figures 4 and 5 show the relative dose fields in the cross-sections of a single object.

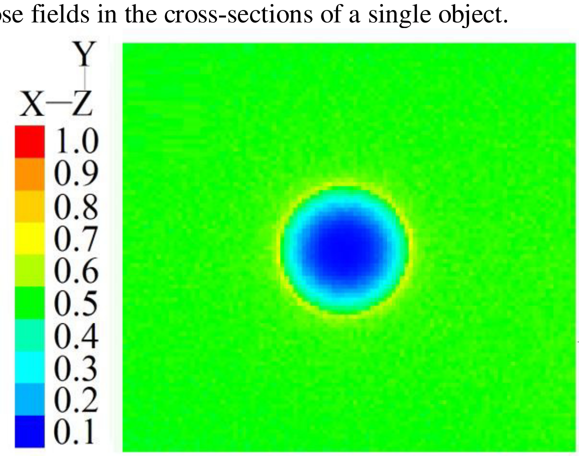

Figure 4: Dose profile of single spherical object after double side irradiation in central horizontal (X-Y) cross-section.

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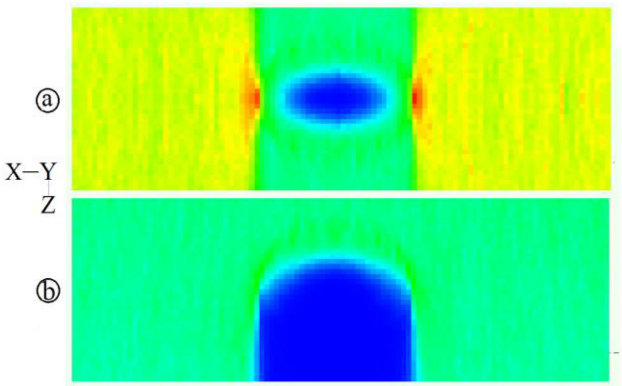

Figure 5: Dose profile of double side (a) and single side (b) irradiation of a single spherical object in central vertical (X-Z) cross-section.

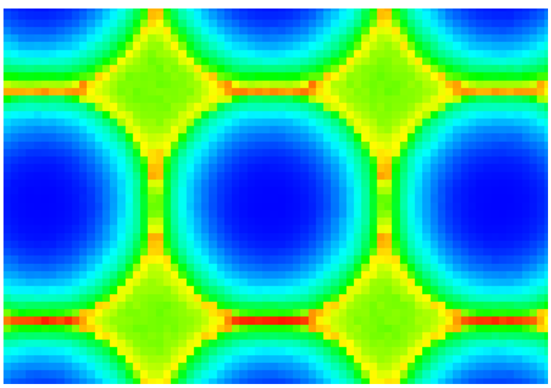

Figure 6: Dose profile of group of objects, laid side by side, after double side irradiation in central horizontal (X-Y) cross-section.

From this study one can note a non-uniform irradiation profile of an object, having a significant dose increase near a surface in horizontal cross-section and dose drop to zero in the center. Consider then a group of objects of this type. Figure 6 shows the horizontal (X-Y) cross-section of irradiated group of objects. Here we can note the increase of dose peak in points of contact of the objects.

The inhomogeneity of dose distribution can be seen from Fig. 7, which shows dose peaks in distribution along central axial lines of an object.

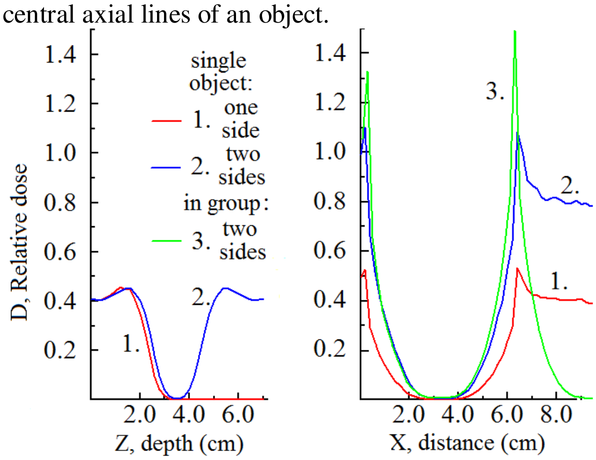

Figure 7: Comparison of the dose profiles in object by depth and distance for one- and two-side irradiation.

From figure 7 one can see that doses of some object parts differs in 3 times, which is not acceptable for food irradiation. To avoid this dose peaks, a special layer of material of 2-3cm thickness and same density, with nests for objects can be used, which covers the central horizontal plane and a few centimeters above and below. With this dummy material, more uniform dose can be obtained, as shown on Fig. 8.

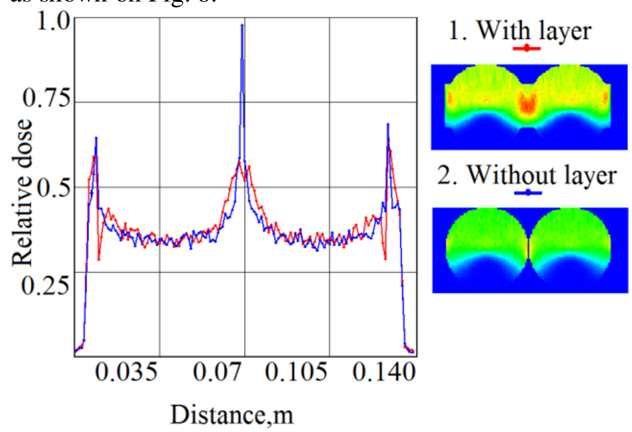

Figure 8: The effect of adding layer of additional material to eliminate a dose peak between two contacting objects

CONCLUSION

Irradiation of food products by electron beam requires the preliminary development of the irradiation technique, taking into account the dose distribution in objects.

To control the effectiveness of the irradiation method used, computer modeling should be carried out to determine the profile of irradiation doses of the objects and the areas of overexposure or under-exposure.

Using code "BEAM SCANNING", a simulation of series of experiments on “Raduga” installation was performed. From study, when irradiating individual objects far from each other, the dose is less homogeneous, so objects should be packed tightly.

In irradiation of spherical objects there is a small dependence of the dose profile on the way the objects are laid, which consists in the overexposure of objects at their contact points. This inhomogeneity can be reduced by using special layers, covering the contact points.

The energy of the electrons from industrial radiation installations is not sufficient for a uniform irradiation of the entire volume of such objects. The irradiation zone covers a near-surface region of thickness up to 2 cm with a maximum at the surface of the object. Such an effect is optimal for suppressing pathogenic microorganisms living on the surface.

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