



Numerical investigation of absorption dose distribution of onion powder in electron irradiation system by MCNPX code

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Abstract: Absorption dose distribution of onion powder in electron irradiation system has been numerically investigated by using of MCNPX (Monte Carlo N-Particle extended) software package and the real parameters of the Rhodotron Accelerator at Yazd Radiation Processing Center (YRPC) of Atomic Energy Organization of Iran (AEOI). The simulations were carried out for the cases in which the onion powder was irradiated by one sided and double-sided electron irradiation and with homogeneous and inhomogeneous sample structures. The line dose profiles and surface dose profile, as well as iso-dose profiles for different depths, and 3D profile of dose distributions in each case were also studied. The simulation results indicated that the dose distribution for double-sided irradiation is uniform and its maximum is in the center. The results also showed that the maximum of depth-dose curve on one-side and double-side irradiation is up to maximal value of 33 kGy and 44 kGy, respectively.

Keywords: Electron beam irradiation; Dose distribution; Rhodotron accelerator, MCNPX code

I. Introduction

One of important method to treat objects for a kind of industrial purposes such as the food industry is electron beam processing or electron irradiation. High intensity and high energy electron beam (approximately 5-10 MeV) are widely used to radiation processing of a kind of products. Rhodotron accelerator is an important source which is used for electron irradiation.

When a product is undergone electron irradiation of rhodotron accelerator, all parts of the sample do not receive an identical dose. Therefore the dose distribution in the product is non-uniform. On the other hand, determination of dose value and situation, dose minimum and maximum values in the product boxes is also important for irradiation processing. Dose value depends on several parameters of products and radiation beam such as size, density, homogeneity or heterogeneity of products and irradiating condition, the frequency of the beam cross-body exposure, the width of the scanning beam, beam energy, beam current intensity and conveyor speed [1]. Another important parameter in the electron beam irradiating is product thickness. The dose distribution is not in the optimum condition, if the product thickness was more than the penetration depth of the electron beam. In this case, the best way is using the double-side irradiation. Due to the short penetration depth of electron beam, the electron beam and product interaction is occurring on the surface [2,3]. Hence, double-side irradiation is used for the products with the thickness more than electron penetration depth to enhance the electron penetration in the product.

In this research, the absorption dose distribution of onion powder in the electron irradiation system was investigated by using MCNPX code software package and utilizing real parameters of rhodotron type electron accelerator available at the Yazd Radiation Processing Center (YRPC) of Atomic Energy Organization of Iran (AEOI). In this simulation, to determination dose distribution of onion powder, one-side and double-side irradiations in two cases i.e. in homogeneity and heterogeneity states of products have been performed. In each case, depth dose distributions, surface dose distributions in different depths, iso-dose curves in different depths, and three dimensional dose distributions in different depths have been also investigated.

II. Simulation Parameters and Procedure

In this research, the simulation has been performed to determine of absorbed dose distribution of onion powder by using the real geometry of irradiation system, and real parameters of the 10 MeV energy electron accelerator at the Yazd Radiation Processing Center (YRPC) and utilizing MCNPX software package. The simulation has been done for the products which their whole volume package filled (homogeneous cases) and for products which their whole volume not filled and parts of the package was empty (inhomogeneous case). The dose distribution has been studied for both directions, along the conveyer motion and scanning electron beam in different depths. Schematic of arrangement of product to electron beam irradiation on the conveyer is shown in the Fig. 1.

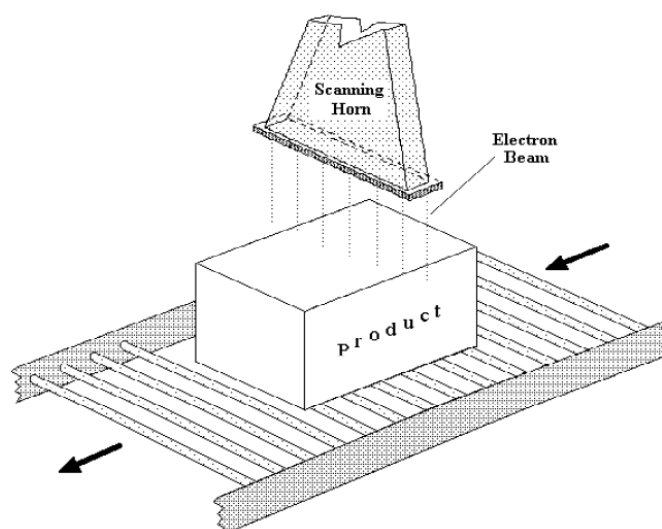


Fig. 1. Schematic of electron beam irradiation of products in Radiation Processing Center

The simulation parameters which were used in this research are related to the electron accelerator that was established at the Yazd Radiation Processing Center (YRPC) at 1997. This electron accelerator is high-energy electron accelerator Rhodotron TT200 type. The system is provided with 5 and 10 MeV electron energies with the maximum available beam current of 8 mA, and a scan width of 100 cm, at a scan frequency of 100 Hz. The accelerator power 100 kW, Rhodotron TT200 type, already has proved to be stable at 250 kW for many hours. The machine is also equipped with a scanning horn with a scan width of 100 cm, at a scan frequency of 100 Hz and is also equipped with a variable-speed conveyor to pass the materials under the scanned beam. The characteristics of the electron source are listed in the table. 1.

Table 1. Characteristics of electron source which are used in the simulation according to YRPC
Rhodotron electron accelerator parameters

Beam energy	Current	Conveyer speed
10 MeV	4 mA	1.8 cm/s

The electron beam is received from the source with spatial distribution which acts as a surface source with 50 cm length and 48cm width. When the products pass from the irradiation position, the beam also scans it in the vertical direction. Since MCNPX could just simulate the constant geometry and could not simulate its motion, hence, it is assumed that all product surfaces are irradiated by the electron beam.

The electron beam considers as the parallel beam to the product. In the one-side irradiation, a surface source is used on one side of the product, and in the double side irradiation, two surface sources with same size and distance from the product are used. After tally calculation, to the exact determination of dose distribution, the parameters and coefficients related to the conveyer speed, current intensity, and product density are added to MCNPX code. The MCNPX code, then determines the dose distribution by finding out it on the different cell which considered in the product. Since supposed product geometries for inhomogeneous and homogeneous irradiation are different, the bulk of matter cells in two cases and therefore the simulation coefficients are different. As mentioned before, the product under study is onion powder which is commonly used in irradiation studies. The characteristic parameters of onion powder which were used in the simulation are listed in the Table.2.

Table 2. Characteristic parameters of onion powder which is used in the simulation based corresponding to Rhodotron accelerator parameters at YRPC

Homogenous product		
Matter	Density	Coefficient of dose calculation
Onion powder	0.7	4.42×10^4
Inhomogeneous product		
Matter	Density	Coefficient of dose calculation
Onion powder	0.7	1.11×10^5

The homogeneous product which is used in the simulation is considered as a rectangular cubic with dimensions 11cm × 33 cm × 48 cm. This configuration is selected based on the packages which are irradiated in YRPC.

Inhomogeneous geometry is changed depth dose distribution in the inhomogeneous regions and their neighborhood, which causes to uniformity of absorbed dose in the different depths. To reduce the errors and run time of the code, the variance reduction technique and a cutoff technique for energy at 0.01 MeV have been used. In this case, the error value was less than 2%.

III. RESULTS AND DISCUSSION

Figure 2 (a, b) shows the dose distribution along the conveyor motion in different depths for homogeneous onion powder product under one-side and double side irradiation, respectively. As shown in the Fig. 2 (a), in the one-side irradiation, the dose distribution increases and then decreases with depth. As well as, the results indicate that the dose distribution has asymmetric form. The curve slopes in the two ends of the graph show the dose variation rate in two adjacent cells inside the product. The results also show that the parts of products which is at the edges absorb lower dose. The obtained results have good agreement with the references [4, 7].

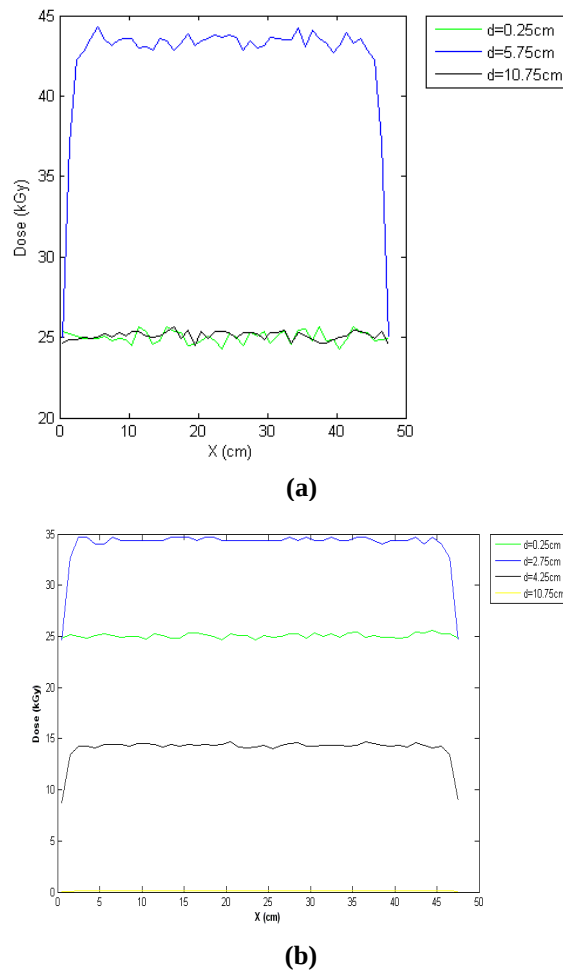


Fig. 2. Dose distribution along the conveyor motion in different depths for homogeneous onion powder, and 10 MeV electron beam. a) One- side irradiation, and b) double-side irradiation

The absorbed dose differences in the different depths are considerable in the one-side irradiation. As shown in the Fig. 2, the absorbed dose value in depth 2.75 cm is 35 kGy and in depth 4.25 cm, is 15 kGy. The differences are indicated that irradiation method should be modified. To improve the irradiation method, and to obtain uniform absorbed dose distribution in the whole product package, the product packages with lower depth can be used. As well as, irradiation from different angles can be performed. The double-side irradiation is one of important methods can be used to improve the absorbed dose distribution which its results are shown in the Fig. 2 (b).

Figure 3 (a, b) shows the depth dose distributions in homogeneous onion powder under one-side and double-side irradiation, respectively. Depth dose distribution under one-side irradiation is shown in the Fig. 3 (a). The difference between absorbed dose in different depths is clearly observed in this Fig. As shown in this Fig, up to the 4 cm depth, due to increasing of secondary electron creation from the atoms and beam interaction, the

absorbed dose increases, then, due to decrease of beam intensity, the absorbed dose decreases [5, 6]. On the other hand, double-side irradiation causes that the inside parts of product receive more doses from two sides, so the maximum depth of two sides overlap. As shown in the Fig. 3 (b), the two peak overlaps and therefore, the maximum dose is 45 kGy in the center.

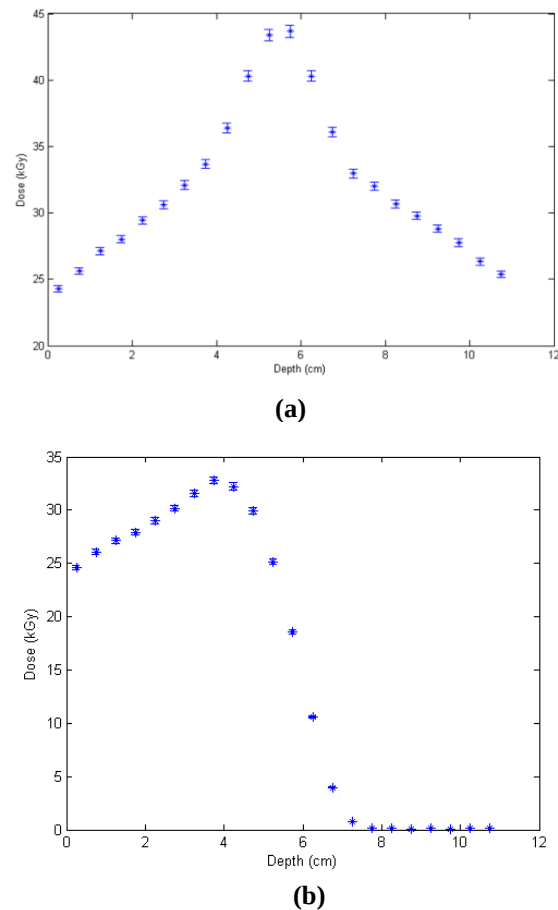
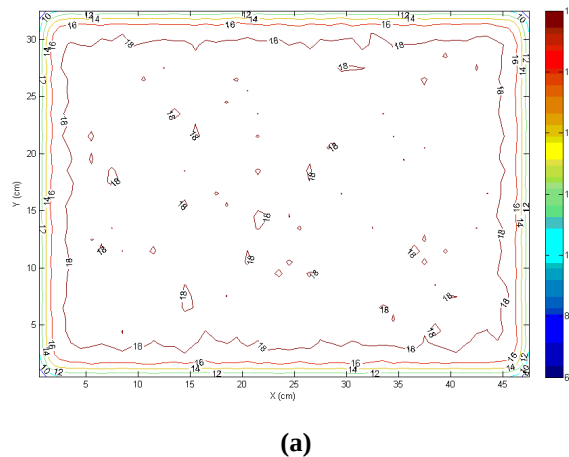


Fig. 3. Dose distributions in different depths for homogeneous onion powder, and 10 MeV electron beam. a) One- side irradiation, and b) double-side irradiation

Fig 4 (a, b) shows the iso-dose curves for the 5.75 cm depth under one-side and double-side irradiation respectively which exhibit the dose distribution inside the product. This curve provides the possibility of survey of dose uniformity in all surfaces under irradiation. The most surface in this depth have been covered by curve 32 kGy. In the other word, in this depth, more than 90% of products receive a uniform dose of 32kGy. The iso dose also decreases with increasing depth in the one-side irradiation which causes to obtain asymmetric curves. While, in the double-side irradiation, iso-dose increases, so that the first and last layers have the same dose.



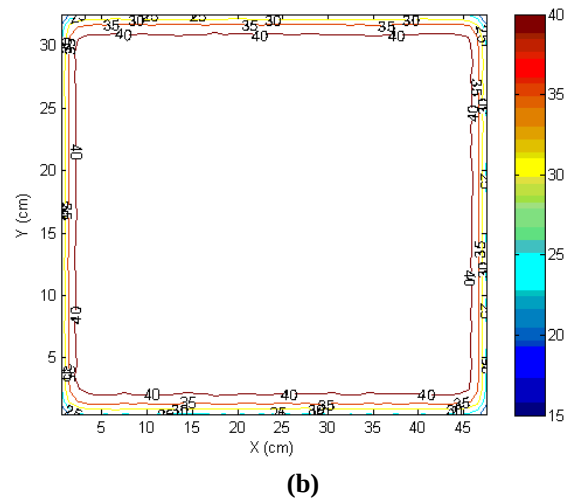


Fig. 4. Iso-dose distributions in 5.75cm depth for homogeneous onion powder, and 10 MeV electron beam. a) One- side irradiation, and b) double-side irradiation.

Figure 5 shows the 3 dimensional (3D) dose distribution in 5.75 cm depth. The 3D dose distribution could use to observe absorbed dose variations by the cells in the defined depth. It also shows that how absorbed dose changes in the regions which are under irradiation respect to other regions. As shown in this Fig, the dose uniformity has been preserved in the double-side irradiation. It also shows that the absorbed doses decrease up to 25 kGy in the boundaries and 15 kGy in the edges. In one-side irradiation, the 3D dose distributions decrease in the lower depths and causes non-uniformity of dose distribution in those depths. While the double-side irradiation causes of increasing dose distribution due to uniformity of dose distribution and higher electron scattering.

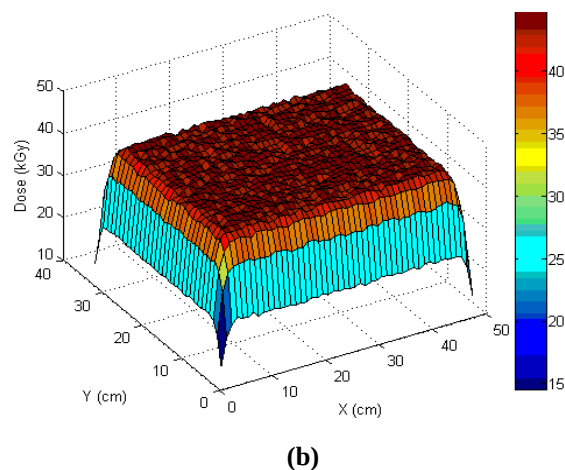
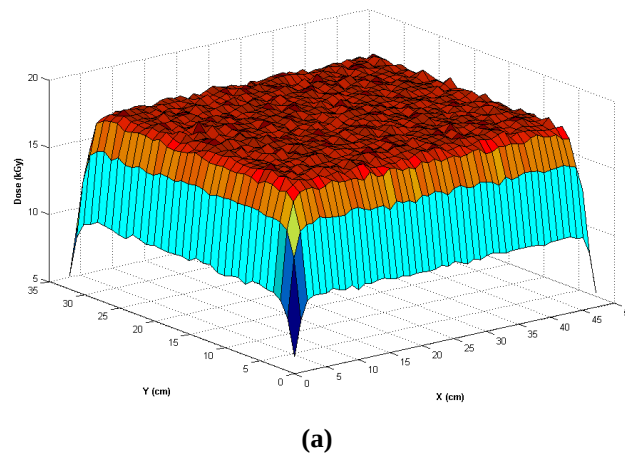


Fig. 5. Three dimensional dose distributions in 5.75cm depth for homogeneous onion powder and double-side irradiation

The dose distribution along the conveyor motion in different depth of inhomogeneous product and one-side irradiation is shown in the Fig. 6. As well as, Fig. 7 displays the depth dose distribution in inhomogeneous parts of inhomogeneous product of onion powder under one-side irradiation. As shown in this Fig, the absorbed dose is too low on the part which includes air. Therefore, the absorbed dose increases in lower depths. On the other hand, in lower depths just under air layer, the dose value increases due to higher electron scattering. In the one-side irradiation, the product does not receive any dose in the parts which including air. Then the dose distribution increases with increasing depth.

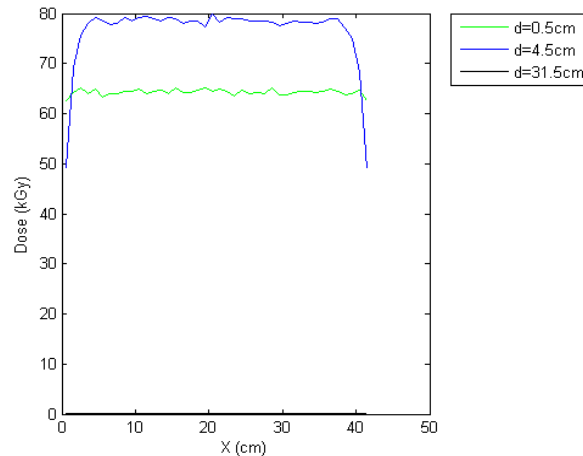


Fig. 6. Dose distribution along conveyor motion in different depth of inhomogeneous product and one-side irradiation of 10MeV electron beam

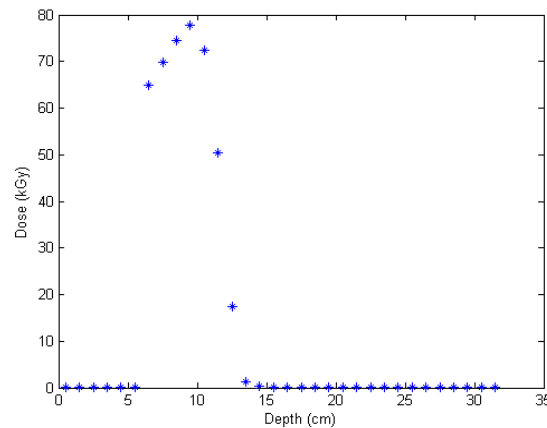


Fig. 7. Depth dose distribution in inhomogeneous parts of the product for one-side irradiation

IV. CONCLUSION

Dose distribution of onion powder under electron irradiation has been numerically studied by using of the MCNPX software package and the real parameters of the Rhodotron Accelerator at YRPC of AEOI. The simulations were performed for one-side and double-side electron irradiation and with homogeneous and inhomogeneous products. The line dose, surface dose and iso-dose profiles for different depths, and 3D profile of dose distributions in each case were also investigated. The simulation results showed that the dose distribution for double-sided irradiation is uniform and its maximum is in the center. The results also showed that the maximum of depth-dose curve on one-side and double-side irradiation is up to maximal value of 33 kGy and 44 kGy, respectively.

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