TẠP CHÍ KHOA HỌC & CÔNG NGHỆ ĐẠI HỌC DUY TÂN
DTU Journal of Science and Technology 01(44) (2021) 51-58

TRƯỜNG ĐẠI HỌC DUY TÂN
DUYTAN UNIVERSITY

Investigation of dose distribution inside Lo Ren Star apple irradiated by 10 MeV electron beam using Monte Carlo simulation

Khảo sát phân bố liều hấp thụ trong trái vú sữa chiếu xạ bởi chùm điện tử 10 MeV sử dụng mô phỏng Monte Carlo

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(Ngày nhận bài: 20/02/2021, ngày phản biện xong: 11/03/2021, ngày chấp nhận đăng: 12/03/2021)

Tóm tắt

Investigation of electron absorbed dose distribution inside a Lo Ren star apple irradiated by 10 Mev electron beam has been performed based on Monte Carlo simulation using the MCNP4c code. Dose uniformity ratio (DUR) inside the Lo Ren star apple has also been evaluated and optimized using additional medium density fiberboards (MDF) outside the carton box. The DUR inside the fruit without using the additional MDF boards was estimated of about 2.47, which is excessively high for fruit irradiation compared to a desirable value of less than 1.5. By optimizing the arrangement and thickness of the MDF boards, the DUR inside the fruit can be reduced to about 1.42. This is a desirable value for fruit irradiation.

Keywords: Lo Ren star apple; dose uniformity ratio; electron beam.

Abstract

Nghiên cứu khảo sát phân bố liều hấp thụ trong trái vú sữa Lò Rèn chiếu xạ bằng chùm điện tử 10 Mev được thực hiện bằng các mô phỏng Monte Carlo sử dụng chương trình MCNP4c. Hệ số đồng đều của liều hấp thụ (DUR) trong trái vú sữa Lò Rèn cũng được khảo sát và tối ưu hóa thông qua việc sử dụng các tấm chắn MDF. Kết quả cho thấy hệ số DUR bên trong trái vú sữa không sử dụng các tấm chắn MDF là khoảng 2.47, khá lớn để áp dụng cho chiếu xạ trái cây so với giá trị mong muốn dưới 1.5. Thông qua việc tối ưu cách sắp xếp và kích thước của các tấm chắn MDF, hệ số DUR có thể giảm xuống 1.42. Đây là giá trị mong muốn trong chiếu xạ thực phẩm phục vụ xuất khẩu.

Từ khóa: Vú sữa Lò Rèn; hệ số đồng đều liều hấp thụ; chùm điện tử.

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1. Introduction

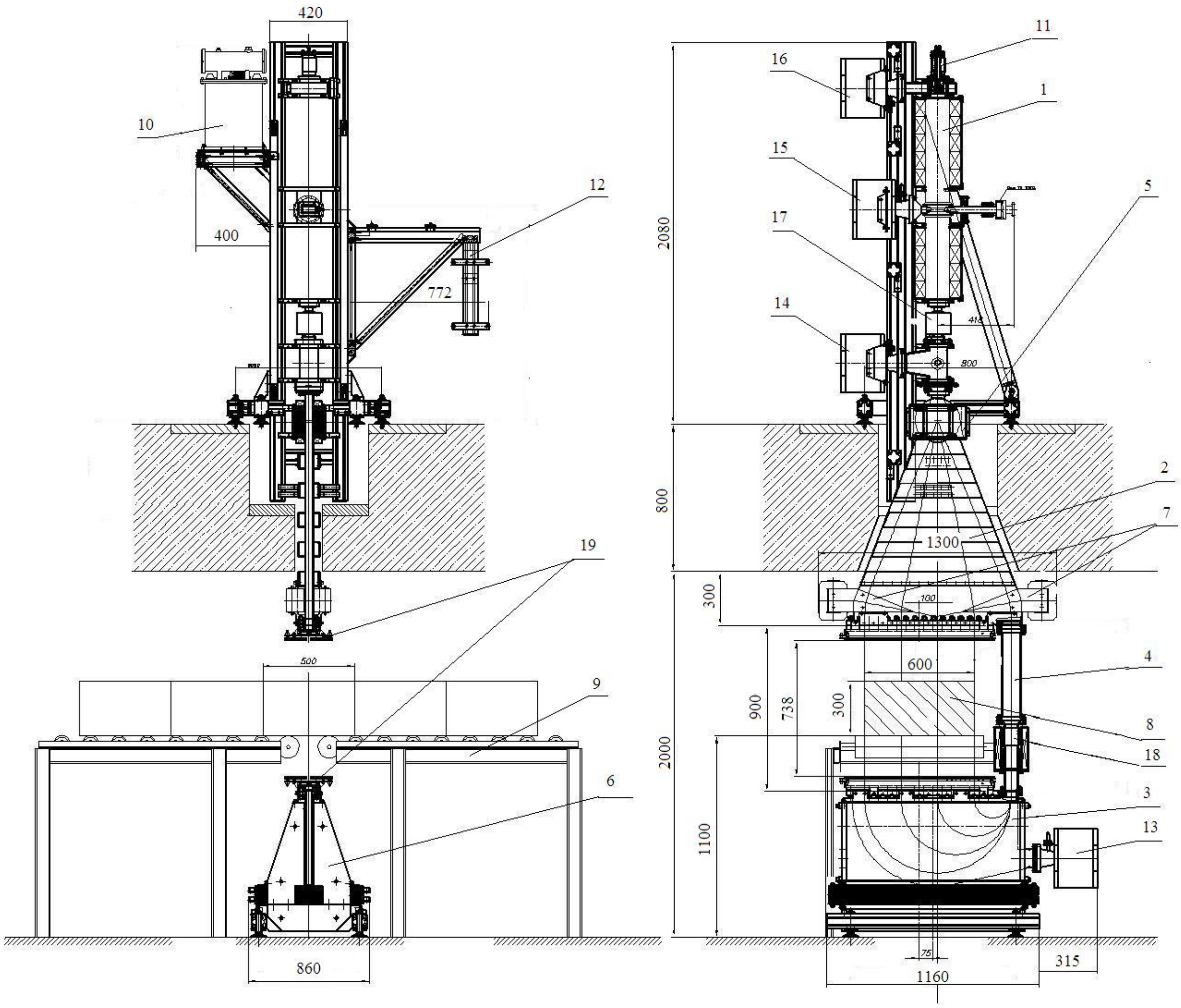
Star apple, one of the agricultural specialties of the Mekong Delta in Southern Vietnam, is being favored in both domestic and international markets. A mature Lo Ren star apple has an average mass of 200-300 g and the diameter of about 5-7 cm. The quality of Lo Ren star apples can only be preserved for 3-5 days after harvest in ambient conditions [1] [2]. Therefore, it is a challenge to preserve the quality of the fruits long enough after harvest for the exportation activity. Ionizing irradiation using gamma ray, electron beam or X-ray is a powerful technique to lengthen the postharvest life of fruits by preventing the growth of living organisms [3] [4] [5]. The effect of irradiation depends on the absorbed dose. For instance, irradiation dose greater than 1.0 kGy can prevent the fungal infection. The doses in the range of 1.0-10 kGy reduce microbial loads on food. The doses from 10 to 25 kGy kill most of fungi and bacterial pests. While doses higher than 25 kGy sterilize medical equipment, hospital food and pet food [5]. However, the dose greater than 600 Gy could reduce the quality of the fresh fruits, e.g. sensory quality of odor, flavor, appearance and vitamin content, while higher doses would cause more damage [5] [6] [7]. According to APHIS 2016, the exported fruits from Vietnam are required to be irradiated at a minimum absorbed dose of 400 Gy using one of the three irradiation sources [8]. Therefore, it is desirable to irradiate the fruit by a minimum dose of 400 Gy, whereas the maximum dose should be lower than 600 Gy to preserve the fruit quality. This means that the dose distribution inside the fruit should be kept uniform, and the dose uniformity ratio (DUR), which is defined as the ratio of highest to lowest doses inside the product, should be lower than a desirable value of 1.5.

The present work aims at investigating the absorbed dose distribution inside the Lo Ren star apple irradiated by double-sided electron beam based on Monte Carlo simulations using the MCNP4c code. Since the size of the Lo Ren star apple is quite small (diameter of 5-7 cm) compared to a desirable value of about 9.6 cm used for food products irradiated by 10 Mev lectron beam, the dose distribution inside the fruit would be nonuniform, and the DUR would be excessively high. To treat the nonuniformity of dose distribution, the use of wooden boards, i.e., medium density fiberboards (MDF), arranged outside of the carton box of the fruits has been proposed. Monte Carlo simulations have been conducted to optimize the arrangement and the thicknesses of the MDF boards in order to minimize the DUR inside the fruit.

2. Materials and methods

2.1. UERL-10-15S2 linear accelerator

The UERL-10-15S2 linear accelerator supplied by Corad Service Ltd, Russia is a common system used for industrial irradiation applications of foods, fruits and medical devices, etc [9]. This facility was equipped at Research and Development Center for Radiation Technology in 2012 for generating 10 MeV electron beam with the intensity of 1.5 mA. The maximum power of the EB is 15 kW. Fig. 1 depicts the cross-sectional view of the UERL-10-15S2 linear accelerator. The system consists of double-sided EBs from upper and lower sides. The irradiated products are transported by a conveyor system. The irradiation dose for specific purposes can be controlled by setting up the operation parameters. In particular, to produce the irradiation dose of 400 Gy of each beam, the system was set up at pulse beam frequency of 35 Hz, scan width of 500 mm, conveyor speed of 0.85 m/min and time duration for each pulse of 4 μs.



1 - Accelerating structure (diaphragmatic waveguide);
2 - Chamber of a scanning electromagnet;
3 - Chamber of banding and scanning electromagnet;
4 - Electron beam canal;
5 - Scanning electromagnet;
6 – Banding and scanning electromagnet;
7 - Bending electromagnets;
8 - A box with irradiated products;
9 - The conveyor dragging irradiated boxes through ribbons electron beams;
10 - Electron gun pulse transformer;
11 - Electron gun;
12 - Ferrite isolator (circulator);
13 - 16 - Ion pump;
17 and 18 - Magnetic induction sensors of beam current;
19 - Beam stops.

Fig. 1 Cross-sectional view of the UERL-10-15S2 electron beam facility.

2.2. Monte Carlo simulation

Monte Carlo simulations have been performed using the MCNP4c code to design the arrangement of the MDF boards to treat the nonuniformity of the absorbed dose distribution inside the fruits [10]. The simulations aim at optimizing the arrangement of the MDF boards to reduce the DURs to lower than a desirable value of 1.5. The parameters considered in the design process include the number and thickness of the MDF boards and their arrangement outside the carton box. Fig. 2 displays the arrangement of the MDF boards selected to treat the nonuniformity of the absorbed dose distribution inside the Lo Ren star apple irradiated by double-sided electron beam. Then, the design parameters which need to be surveyed are D1, D2, D3, R1 and R2 as shown in Fig. 2. In the MCNP4c simulations, the number of particle history was chosen as 2.7×10^6 to obtain the statistic error of the calculated absorbed dose rate within 2%.

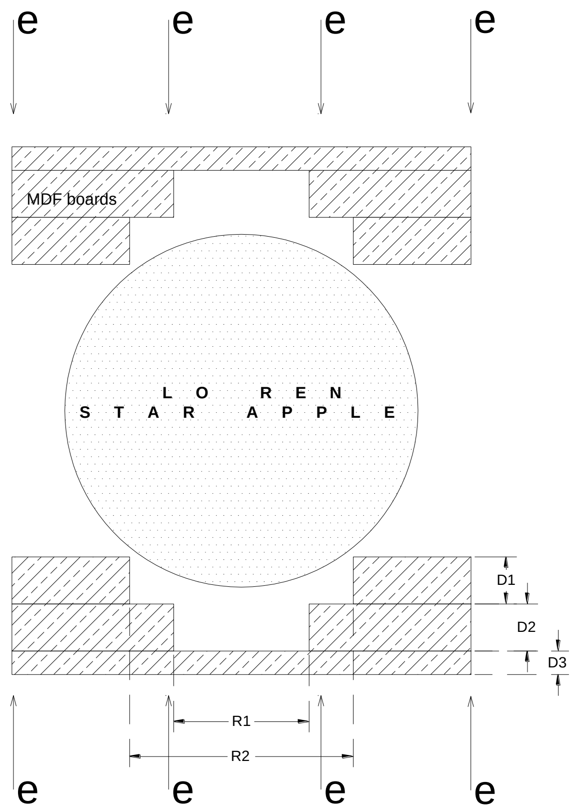


Fig. 2 Model of the Lo Ren star apple with MDF boards using MCNP4c code.

3. Results and discussion

3.1. Dose distribution inside the fruit without MDF boards

Monte Carlo simulation has also been conducted for the Lo Ren star apple irradiated by double-sided electron beam without the use of MDF boards to investigate the absorbed dose distribution inside the fruit. Fig. 3 shows the absorbed dose distribution inside the Lo Ren star apple without the MDF boards. The absorbed dose distribution inside the Lo Ren star apple is relatively nonuniform with high values inside of and on the surface of the fruit. The highest dose is about 1011 Gy is found at the surface of the fruit. This value corresponds to the DUR of about 2.48. Compared to a desirable value of 1.5, the DUR of 2.48 is considerably high for fruit irradiation. Thus, a treatment of dose nonuniformity is necessary in the irradiation of the star apple.

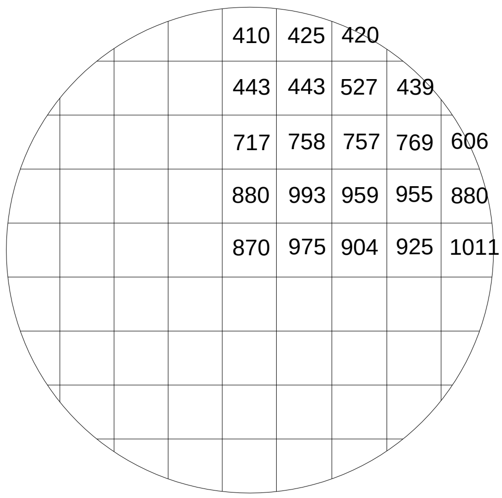


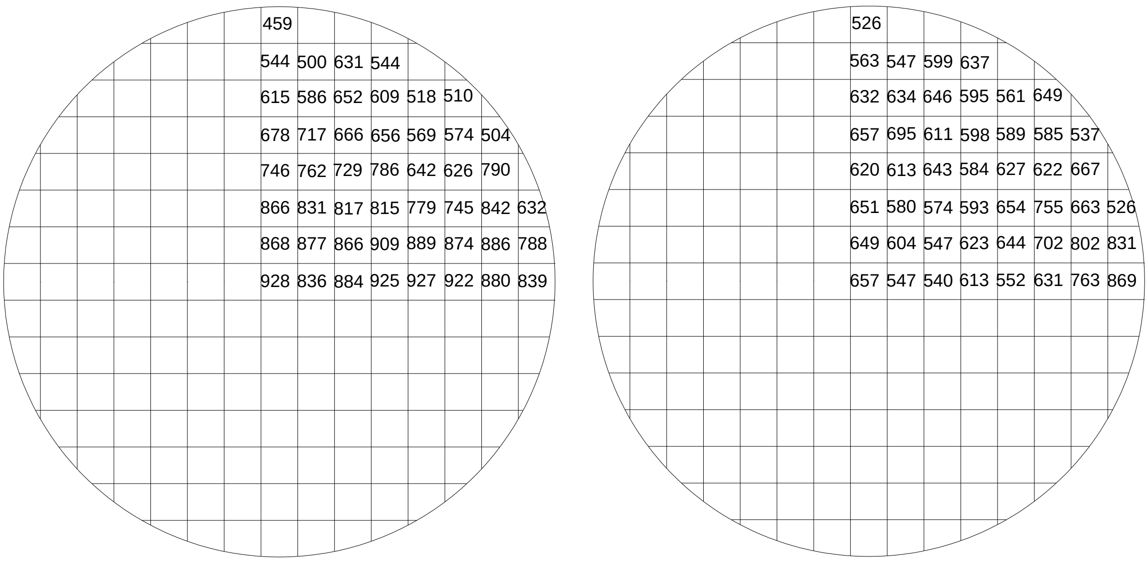
Fig. 3 Dose distribution inside the Lo Ren star apple without the use of MDF boards.

3.2. Dose distribution inside the fruits with the use of MDF boards

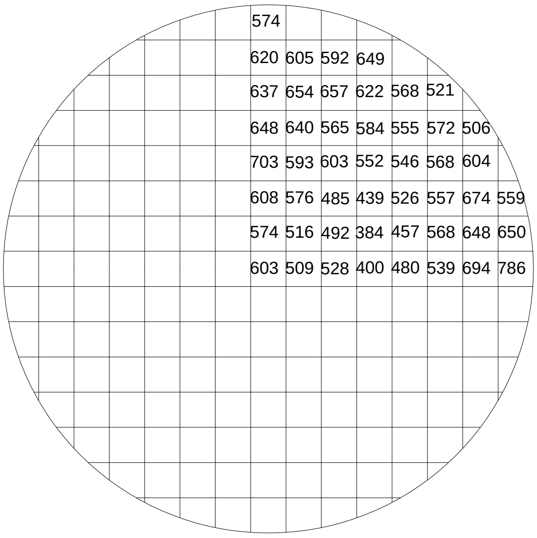
In order to treat the nonuniformity of absorbed dose distribution inside the fruit and reduce the DUR, the use of MDF boards arranged outside the carton box as shown in Fig. 2 has been proposed. Table 1 summarizes the design parameters of the MDF boards selected from seven cases in this survey. Fig. 4 shows the absorbed dose distribution inside the fruit obtained from MCNP4c simulation corresponding to Cases 1-4 of the MDF arrangement. The DURs are reduced to 2.02, 1.65, 2.05 and 1.96 corresponding to Cases 1-4 of the MDF boards. Fig. 5 displays the same quantity as in Fig. 4 but for Case 5-7 of the MDF arrangement. It can be seen that the absorbed dose distributions inside the fruits become relatively uniform with the use of MDF boards compared to that without MDF boards as shown in Fig. 3. Fig. 6 depicts the comparison of the DUR values obtained with the seven cases of MDF arrangement. It can be seen that the DUR is reduced from 2.48 to 1.42-2.05 by using the MDF boards outside the carton box. The lowest DUR value of 1.42 is found with Case 6 with the design parameters presented in Table 1. The results indicate that by using the MDF boards with the optimal arrangement designed by Monte Carlo simulations, the nonuniformity of the absorbed electron dose distribution inside the fruits can be treated effectively. The DUR value of 1.42 for the Lo Ren is less than the desirable value of 1.5.

Table 1: Summary of the design parameters of the MDF boards.

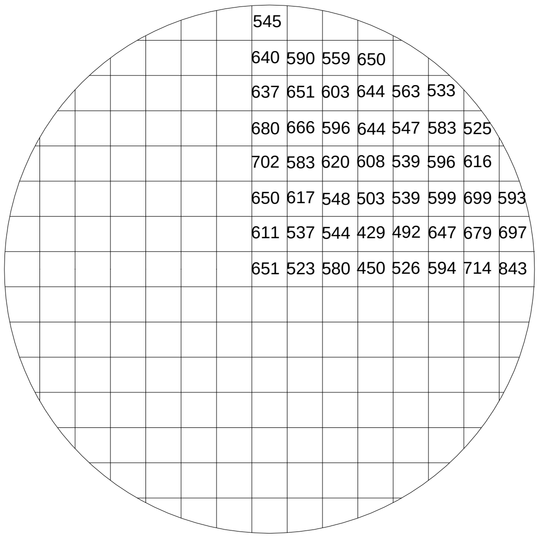
Case	D1 (cm)	D2 (cm)	D3 (cm)	R1 (cm)	R2 (cm)	DUR
1	0.4	0.8	0.8	2.3	3.8	2.02
2	0.8	0.8	0.8	2.3	3.8	1.65
3	0.8	0.8	1.2	2.3	3.8	2.05
4	0.8	0.8	1.2	2.3	4.2	1.96
5	0.8	0.8	1.2	2.3	4.6	1.79
6	0.8	0.6	1.6	2.3	4.6	1.42
7	1.0	0.8	0.8	2.3	4.6	2.03



a) Case 1 b) Case 2

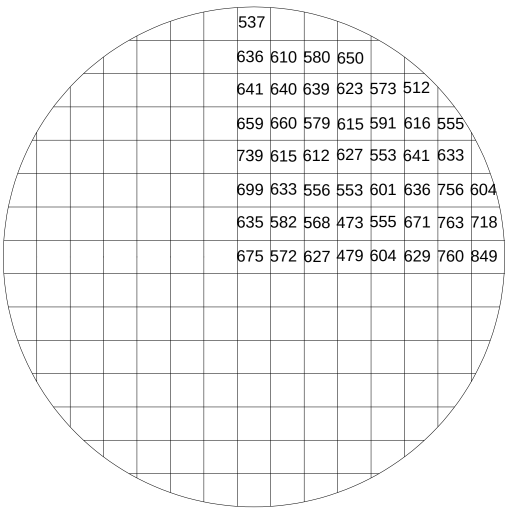


c) Case 3

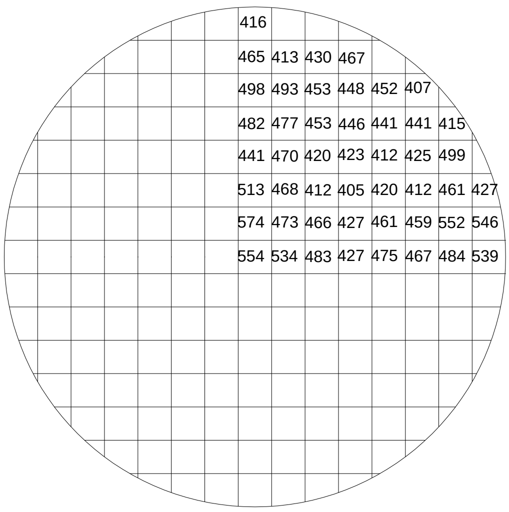


d) Case 4

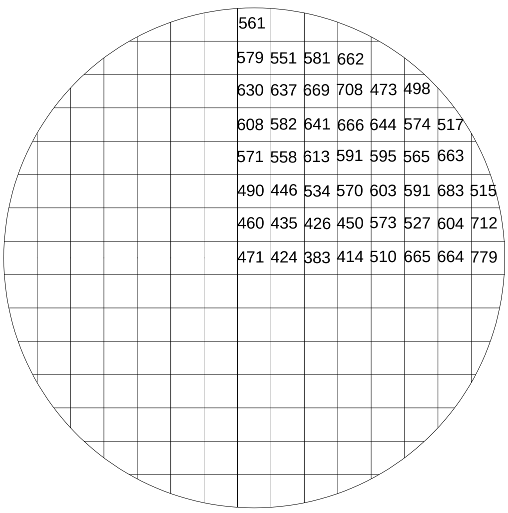
Fig. 4 Absorbed electron dose inside the star apple with seven models of MDF boards.



e) Case 5



f) Case 6



g) Case 7

Fig. 5 Absorbed electron dose inside the star apple with seven models of MDF boards (continued).

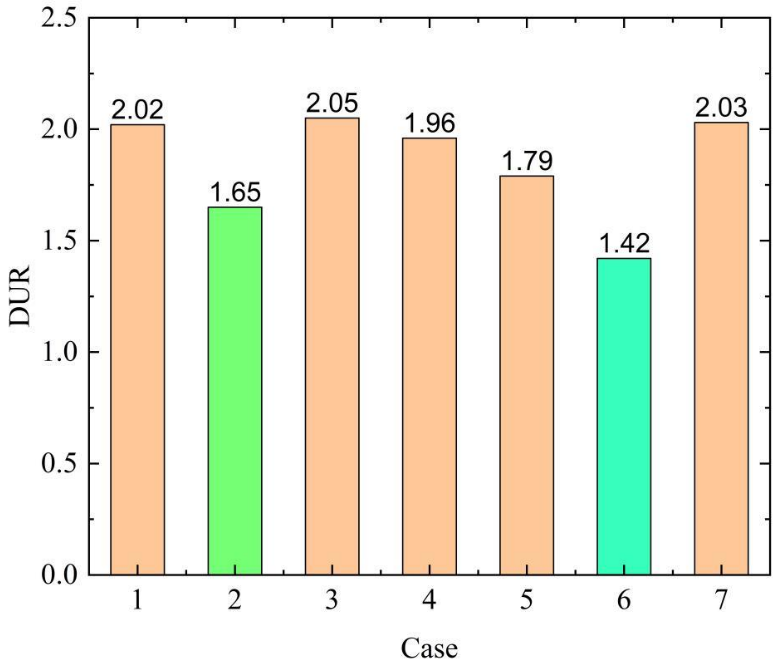


Fig. 6 DURs inside the Lo Ren star apple obtained from MCNP4c simulations.

4. Conclusions

Investigation of the absorbed dose distribution inside the Lo Ren star apple irradiated by 10 MeV electron beam has been conducted based on Monte Carlo simulations. The Lo Ren star apple with the diameter of 5-7 cm were assumed to be irradiated by the double-sided electron beam. The DUR of the absorbed dose inside the fruit is estimated of about 2.47, which is excessively high for fruit irradiation. In order to flatten the absorbed dose distribution and reduce the DUR to lower than 1.5, it is proposed to use additional MDF boards outside the carton box. The arrangement and thicknesses of the MDF boards have been surveyed and optimized based on the MCNP4c simulations. The results show that by optimizing the arrangement of the MDF boards, the nonuniformity of the absorbed electron dose distribution inside the fruits can be treated effectively. The DURs can be reduced to about 1.42. This value is desirable for fruit irradiation.

Acknowledgements

This work was supported by International Atomic Energy Agency under Coordinated Research Project D61024 (Contract Number 18984).

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