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Alanine-EPR dosimetry in 10 MeV electron beam to optimize process parameters for food irradiation

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Absorbed dose in food product is determined and controlled by several parameters of the LINAC irradiation facility as well as those of the product. Standardization of the parameters characterizing the facility parameters, process load and the irradiation conditions collectively termed as 'process parameters' are important for successful dose delivery to the food products. In the present study, alanine-EPR dosimetry system was employed to optimize process parameters of 10 MeV electron beam of a LINAC facility for commercial irradiation of food products. Three sets of experiments were carried out with different food commodities namely, mango, potato and semolina (coarsely ground wheat, local name Rawa) with the available product conveying system of different irradiation geometries in one sided or two sided mode of irradiation. Three dimensional dose distributions into the process load for low dose requiring food commodities (0.25 to 1 kGy) were measured in each experiment. The actual depth dose profile in food product and useful scan width of the electron beam were found to be satisfactory for commercial radiation processing of food. Finally, a scaled up experiment with a commercial food product (packets of semolina) exhibited adequate dose uniformity ratio allowing use of the facility for large scale radiation processing of food commodities.

Keywords: LINAC, Food irradiation, Alanine-EPR, Dosimetry system

1 Introduction

India is world's second largest producer of food and has the potential to become number one by employing new emerging technologies. In this regard, food security is one of the important components of our national development and deals with providing nutritionally wholesome and safe food at an affordable price. Electron beam processing of foods is an important emerging technology for strengthening food security, improving food safety and promoting international trade by phytosanitation to overcome quarantine barriers. Dosimetry is one of the important components of a total quality assurance program for adherence to good manufacturing and good irradiation practices.

Absorbed dose in a food product is determined and controlled by several components of the LINAC irradiation facility as well as the product. Standardization of the parameters characterizing the facility components, process load and the irradiation conditions collectively termed as 'process parameters' is of paramount importance for successful dose delivery to the food products. In the present study, alanine-EPR dosimetry system was employed to optimize the process parameters of 10 MeV electron beam of a LINAC facility for commercial irradiation of food.

2 Materials and Methods

2.1 Preparation of dosimeter

Analytical grade alanine polycrystalline powder [$CH_3CH(NH_2)COOH$], (Sigma Chemical Co. USA) was used directly as supplied by the manufacturer after adequate calibration[1] as per ASTM 51261. The alanine powder weighing from 75 to 85 mg was sealed in a polyethylene pouch of dimension 10(L)×10 (W)×1(T) mm^3 and exposed to different doses of radiation (200-1000 Gy) in a gamma irradiator (Gamma Chamber 5000, BRIT, India, dose rate 68 Gy/min). The gamma irradiator was calibrated using Fricke standard dosimeter[2].

2.2 Preparation of dosimetry box

In order to measure the absorbed dose inside the product box during 10 MeV electron beam irradiation of food commodities two dummy boxes of Perspex were fabricated of depth 40 and 90 mm for one sided and two sided irradiation geometry, respectively as shown in Fig. 1.

Fig. 1 — Dummy product boxes made of Perspex with depth 40 mm and 90 mm for 10 MeV e-beam food irradiation dosimetry experiments

2.3 Irradiation of food with 10 MeV e-beam

A series of experiments were carried out with 10 MeV e-beam machine at Electron Beam Centre, Bhabha Atomic Research Centre. Alanine dosimeters were fixed throughout the volume of the product boxes to obtain distributions of dose inside the food commodities. Based on the initially set machine parameters and absorbed dose profiles for 10 MeV e-beam, the Perspex box of 40 mm depth was employed to find out the depth dose profile and useful scan width for food irradiation. The typical parameters of e-beam machine employed in the experiments were *R F* Power 2.75 MW, *R F* Current 165 A, Beam current 60 mA, Beam power 2 kW and irradiation time 1 min 50 s, scanning frequency 2.1 Hz and peak scanning current 1000 mA. In all the experiments, irradiation was carried out with two experimental conditions. Firstly, with one sided irradiation and thereafter, with two sided irradiation geometry. Different foods such as mango, potato, semolina (Rawa) were used as the media of the absorbed dose. After exposure, the dosimeters were evaluated using X-band EPR spectrometer (BRUKER, Germany).

3 Results and Discussion

In order to study, the efficacy of electron beam irradiation of food at 10 MeV, LINAC facility, a series of dose measurement experiments were carried out to standardize and optimize the beam parameters.

3.1 Experiments to standardize beam parameters for food irradiation

Initially, the base line information on suitable machine parameters of 10 MeV e-beam accelerators for food irradiation was found out by two sets of experiments. In both the experiments, mango was used as the medium of absorbed dose. The commercially available mango cartons of dimension 340 (L)×250 (W)×90 (D) mm^3 were filled with mangoes along with alanine dosimeters and exposed with e-beam of energy 10 MeV. The radiation dose was delivered with moving conveyor and the distance of beam window from the product box was 900 mm. The machine parameters were set for a target minimum dose (D_{min}) of 400 Gy which is commercially important D_{min} for the quarantine treatment of mango. The minimum and maximum doses for both the irradiation geometries were considerably low in comparison with the desirable target dose of 400 Gy. In case of one sided irradiation, under dosage could be because of the insufficient e-beam energy to penetrate a depth of 90 mm through the product of bulk density 0.58 gm/cc. In addition, for both the irradiation geometries, the wide difference between actual absorbed dose and desired target dose was attributed to the large distance of 900 mm between the e-beam scanning window and the top surface of the product box. Because, wide distance introduced a large electron scattering before reaching the target surface of the product box.

In order to confirm the interpretations based on the preliminary experimental results, another two sets of experiments were carried out keeping all the beam parameters and product box dimension same but with a reduced e-beam scan window to product distance of 400 mm. In both the experiments, the desired minimum dose was set as 400 Gy and potato was used as the medium of absorbed dose of equivalent bulk density of 0.56 gm/cc. First experiment was with two sided irradiation and D_{min} was measured as 454 Gy at the top and bottom planes and D_{max} of 540 Gy was observed at the middle plane as shown in Fig. 2. However, for second set of experiment with one sided irradiation geometry the D_{min} was not adequate because of the larger depth (90 mm) of the product box for 10 MeV e-beam.

3.2 Evaluation of beam characteristics and optimization of process parameters

In order to standardize the product box dimension for one sided and two sided irradiation geometries two dummy product boxes made of Perspex were fabricated as explained earlier. Two sets of experiments were carried out to study the actual depth dose distributions and useful scan width available for food irradiation for both the irradiation geometries with the dummy product box of thickness 40 mm. Semolina (Rawa) was used as a medium of absorbed dose. The desired target dose was 400 Gy for the first set of experiment. Figure 3(a and b) shows the scan width and depth dose profile inside the 40 mm thick

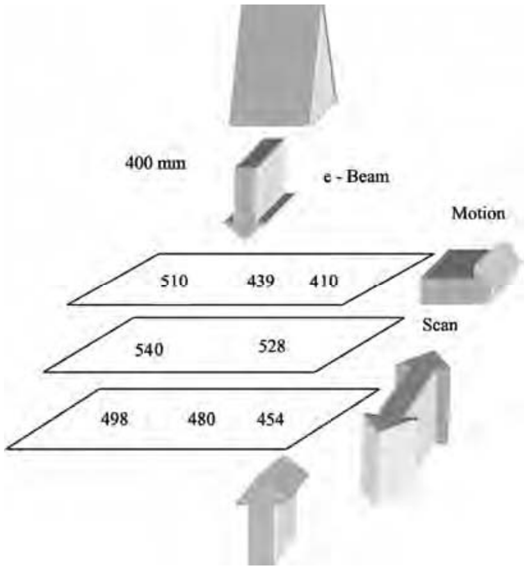

Fig. 2 — Schematic diagram of both sided irradiation geometry of 10 MeV e-beam and distribution of absorbed dose inside the product box containing food sample of bulk density 0.58 g/cc

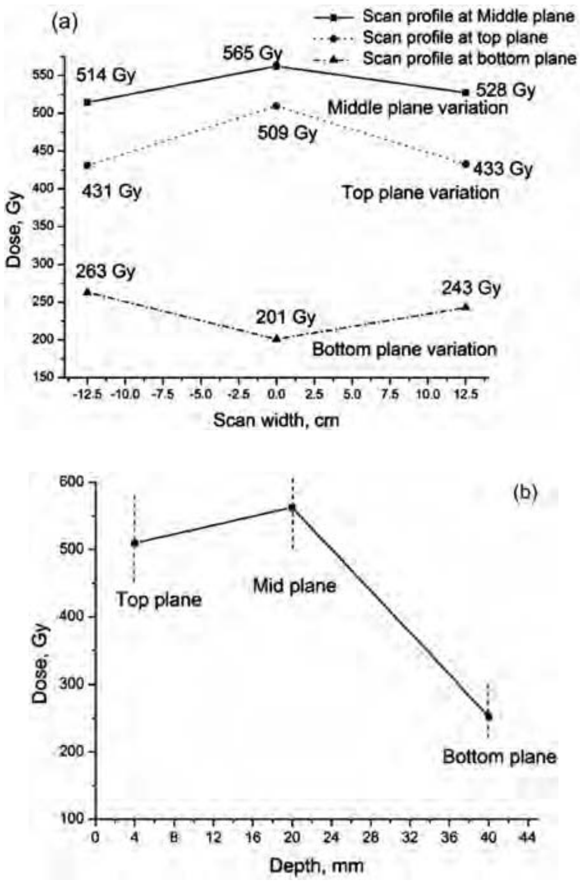

Fig. 3 — (a) Scan profiles in all the planes of the product box (depth 40 mm), (b) depth dose profile for one sided irradiation in semolina medium

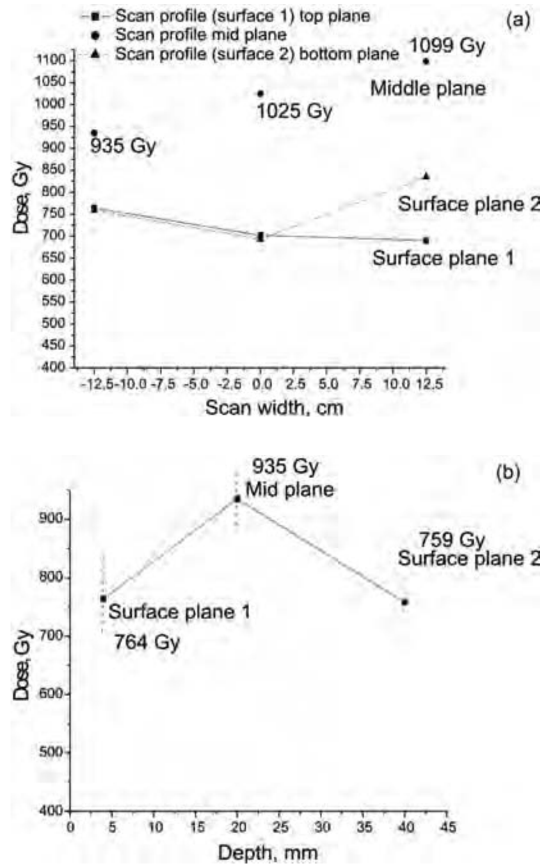

Fig. 4 — (a) Scan profiles in all the planes of the product box (depth 40 mm) and (b) depth dose profile for both sided irradiation in semolina medium

product box for one sided irradiation geometry. The depth dose profile indicated a sharp fall of the absorbed dose towards bottom plane for 40 mm thick process load with 10 MeV electron beam energy. However, the beam scan width profile was observed to be satisfactory. The results suggested that the desired D_{min} can be achieved either by reducing the process thickness to 34 mm or by adjusting the speed of the product movement trolley with acceptable dose uniformity ratio of 1.6.

In case of second set of experiment, the desired target dose was 800 Gy in two sided irradiation geometry with the same product box (depth 40 mm). Fig. 4(a and b) shows the scan profile and depth dose profile for 10 MeV e-beam. A very good dose uniformity ratio of 1.58 was observed for this irradiation geometry with D_{min} 690 Gy.

3.3 A scaled up experiment

In order to establish the standardized process parameters in 10 MeV e-beam for food irradiation a scaled up experiment of radiation processing of commercially available semolina (Rawa) packets was carried out. Thirty packets of semolina were procured from a supermarket. Ten packets were kept as control and remaining lots of ten packets each were exposed to two desired minimum doses of 350 and 650 Gy which were within the required doses range (250-1000 Gy) for insect disinfestation. In the first case, the absorbed D_{min} and D_{max} were measured as 415 and 457 Gy with an acceptable dose uniformity ratio of 1.1. For the second case, the D_{min} and D_{max} were measured as 790 and 902 Gy and dose uniformity ratio was 1.14. In both the cases, improved dose uniformity ratios were observed because of standardized process parameters and lesser packet thickness of 25 mm of commercial semolina.

4 Conclusions

The experimental results established standardized process parameters including beam characteristics, beam dispersion, product handling characteristics and irradiation geometry. Acceptable dose uniformity throughout the product geometry was also achieved with these standardized process parameters. Hence, electron beam irradiation of food products requiring various dose ranges can be carried out using standardized machine parameters and controlled product movement mechanism.

References

1 ISO/ASTM 51261:2002(E). *Standard Guide for Selection and Calibration of Dosimetry Systems for Radiation Processing.*
2 ASTM Standard, E 1026. *Standard Practice for Using Fricke Reference Standard Dosimetry System.*