Application of dose reader CD-07 for depth-dose distribution measurements in the process of microbiological radiation decontamination

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Abstract. Dose reader CD-07 has been introduced for measurements of a dose distribution during dose mapping exercises and for calculations of electron beam energy. This instrument consists of an SP-880 spectrophotometer equipped with a driving motor to move a dosimetric foil across light beam in the front of narrow light aperture. To control the movement of the foil and to present and store the measuring results a specialized software has been developed. In this paper the use of dose reader CD-07 in Performance Qualification of irradiated herbs was described.

Key words: depth-dose distribution measurements • food irradiation • microbiological decontamination

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Introduction

Dose irradiation uniformity during food microbiological decontamination with electron beam is the main problem in process control. Irradiation of food or botanical raw materials is used in order to control the level of microbiological contamination, reduce insect infection, inhibit the germination and extend the shelf life [8]. The irradiation process of food products should be so kept as to achieve the desired purpose and not to exceed the maximum dose of 10 kGy in the whole bulk of product which is approved by WHO [1]. The main factors which determine the depth-dose distribution are type, energy of radiation and product thickness and density. The electron penetration is proportional to the energy and inversely proportional to the product density according to Eq. (1)

$$\text{Penetration (cm)} = (0.524E - 0.1337)/\rho \quad (1)$$

where E is the beam energy in MeV and ρ is the density in g/cm^3. This equation applies to electron energies greater than 1 MeV. The process thickness, which is defined as the depth at which the dose equals the entrance (surface) dose is a crucial parameter [2].

Food products are characterized by different densities which affect the dose distribution. The simplest way to characterize the product in order to process control is grammage F defined as the mass of product per unit of area. The grammage can be easily changed through changing the packaging.

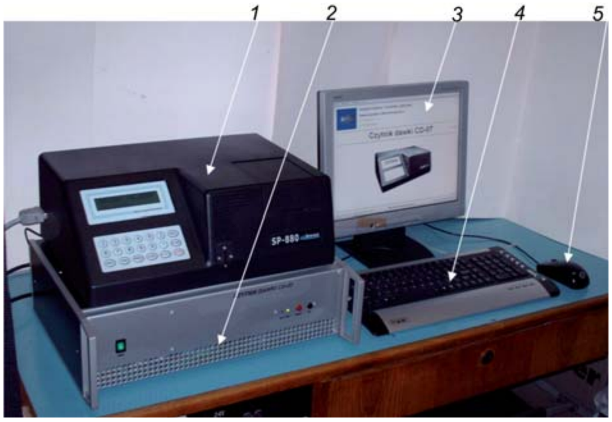

Fig. 1. General view of the dose reader CD-07. *1* – Spectrophotometer SP-880; *2* – electronics unit based on embedded microcomputer; *3* – LCD monitor; *4* – keyboard; *5* – mouse.

The aim of his work was to present the advantages of depth-dose measurement with the use of dose reader CD-07 in the process of food irradiation with electron beam.

Dose reader CD-07

The dose reader CD-07 [7] is designed to measure radiation dose from a dosimetric foil in the form of a long, narrow band during irradiation process. Materials and final products when moving on a conveyor belt are irradiated by an electron beam. The PCV dosimetric foil is placed on the conveyor belt and is irradiated together with utensiles. After irradiation, the foil is seasoned (heated at 70°C for 30 min) and then it is measured with the dose reader. The foil is moved across light beam in the dose reader, the radiation dose is measured along the foil and, at the same time, the dose is displayed at the monitor of the reader. The principle of operation is based on attenuation of light of selected wavelength (on absorbance of dosimetric foil).

A general view of the dose reader CD-7 is shown in Fig. 1. The main component of the dose reader is a spectrophotometer SP-880 produced by Metertech [10]. The standard spectrophotometer was equipped with a driving motor to move a dosimetric foil across light beam in the front of narrow light aperture.

To control the movement of the foil and to present and store the measuring results, specialized software was also developed at the Institute of Nuclear Chemistry and Technology (INCT). A functional diagram of dose reader operation is shown in Fig. 2.

The SP-880 spectrophotometer is a single light beam device. The electronic part of the spectrophotometer consists of a light detector, an analog to digit converter and a microprocessor system that controls operation of the spectrophotometer. In the case of CD-07 dose reader, it transmits also the measuring results of light intensity to foil driving mechanism control through a serial port RS232. Parameters of operation of the spectrophotometer (light wavelength) are selected from the microcomputer program that controls operation of the dose reader as a whole. The embedded microcomputer operates in Windows XP system. All computations, control of measuring cycles, presentation of measuring results, and storage of data in the reader memory are carried out by the microcomputer [6]. The dose reader enables 1) measurements of absorbed dose, 2) measurements of electron energy.

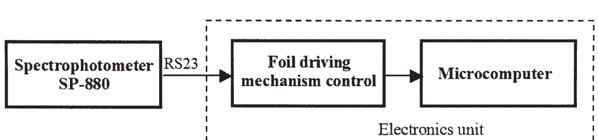

Fig. 2. Functional diagram of the dose reader.

Absorbed dose measurement

During irradiation process, the irradiation dose applied has to be kept within strictly determined limits. It is very important thus, to control if the absorbed doses in the whole volume of irradiate material is kept within the required limits. A measurement of the dosimetric foil is a short time process. Apart from the absorbed dose against length of the foil that is presented, such data as minimum dose, maximum dose and average dose is computed and also given. The absorbed dose is determined from the relation given in Eqs. (2) and (3)

$$\text{dose} = K_d \cdot (A_x - A_0) \tag{2}$$

$$A_x = \log S_x/S_0 \tag{3}$$

where: K_d – calibration coefficient; A_x – absorbance of measured foil; S_x – pulse amplitude of measured foil; S_0 – pulse amplitude without foil; A_0 – absorbance of non-irradiated foil. The corresponding distance to the dose measured is determined from the relation given in Eqs. from (4) to (6).

$$L = k_n * n \quad \text{– distance (mm)} \tag{4}$$

$$k_n = \pi D\,\alpha/360 \quad \text{– distance per one step} \tag{5}$$

$$n = fr \cdot k_s/10 \quad \text{– number of motor steps} \tag{6}$$

where: n – number of steps of the step motor; f – step motor driving frequency (Hz); r – number of readings from the start (one reading every 1/10 s); k_s – step coefficient, when k_s = one full step is made, when $k_s = 0.5$ half step is made; D – diameter of driving roll; α – driving roll angle from one step of the step motor.

Electron energy measurement

Measurement of electron energy is performed according to ISO 51649 [4]. The measurement is based on transmission of electron beam through an aluminium wedge below which a dosimetric band foil is placed [6]. In the energy measurements made at the INCT a PCV foil is used. The wedge together with the foil is placed in a container that is moved with a constant speed across the irradiated field. The width of electron beam and speed of the conveyor should be set so that the absorbed dose is in the range of dosimetric system.

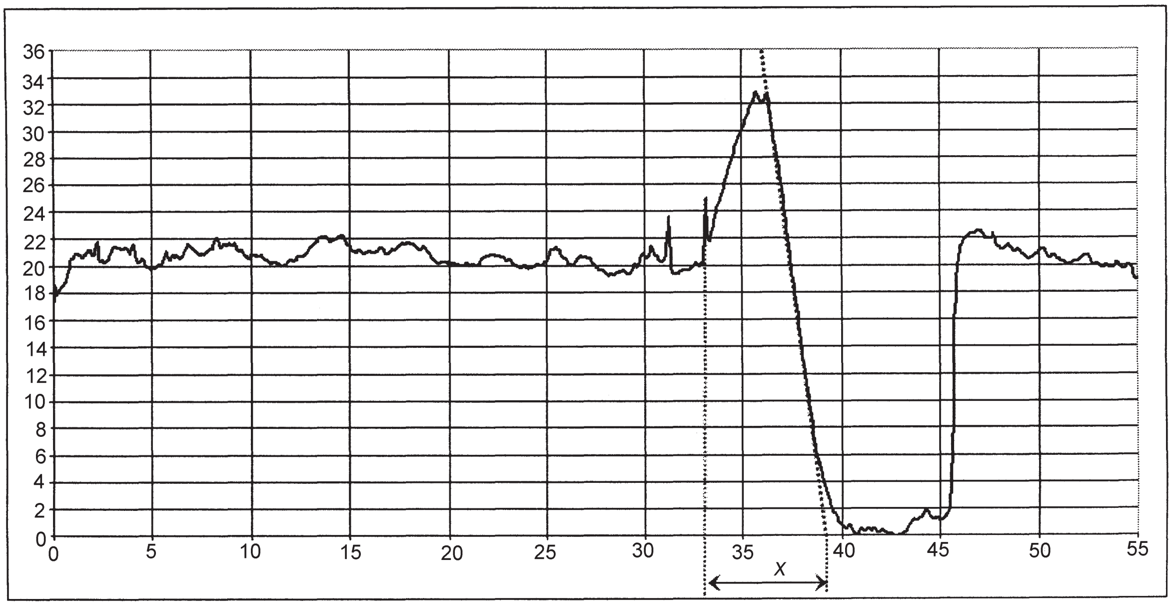

Fig. 3. Example diagram for determination of electron beam energy.

After irradiation, the PCV foil is taken out from the wedge. The foil is then heated at a temperature 70°C for 30 min in order to secure the color of the dosimeter. Such a foil is then measured in the dose reader. An example diagram for the determination of electron energy is shown in Fig. 3.

The electron beam energy is computed from the relation (7)

(7) $$E\,[\mathrm{MeV}] = 5.09 \cdot 0.28x + 0.2$$

where: 5.09 – coefficient; 0.28 – sine of 16° (angle of cutting aluminium block to get the wedge into which the dosimetric foil is put); x – distance between the marker (where the foil enters into the wedge) and the point of intersection of tangent line with zero level as shown in Fig. 3.

Basic parameters of the reader:
- light wavelength: 330...1100 nm;
- photometric range: –0.3...3.5 Abs;
- stability: < 0.003 Abs/h;
- light beam incident on dosimetric foil: 8.5 × 1 mm;
- dosimetric foil length: any longer than 25 cm;
- width of dosimetric foil: 16 mm;
- foil moving speed: 0.5...8 cm/s;
- ambient temperature and relative humidity: 15...35°C, < 85%.

Dosimetric system

Dosimetric measurements during a dose mapping exercise were performed according to ISO 11137-3:2006 [5]. The data obtained from Performance Qualification were used to identify locations and magnitudes of minimum and maximum doses within the product and to show the relationship between these doses and the dose at the monitoring position.

PVC foil was used for dose mapping exercise. These dosimetric system was validated by accredited Laboratory for Measurement of Technological Doses.

This dosimetry system has a high enough spatial resolution to allow measurement of dose gradients that could occur, for example, at material interfaces. For electron beam irradiation, the magnitude of the dose gradients can be several tens of percent over less than 1 mm.

Experiments

The irradiation was performed at the INCT Food Irradiation Plant equipped with an accelerator Elektronika 10-10 capable to generate the beam of high energy electrons (8–10 MeV) [9]. The computer control system has been installed to assure delivery of the desired dose of electrons of energy 8.5–9.5 MeV by controlling accelerator parameters with the use of analog-digital steering system and collecting data under technological conditions. Basing on the dose measurements at adjusted parameters and actual conveyor speed, the system calculates the dose on-line that is stored at the computer hard disc.

For the experiments, homogeneous natural dried plant product characterized by a density of 0.5 g/cm^3 was used. Because the materials were in loose form, they were packed in small bags of amount 500 g and 1000 g to facilitate the placement of dosimeters. In a dose mapping exercise, dosimeters were placed at the surface of a product, at the bottom and between the layers of a product according to a defined pattern. In order to measure the depth dose the bags with material were layered to obtain the maximum $F = 6.8$ g/cm^2 for one and two side irradiation. The surface irradiation dose measured with a graphite calorimeter was 7 kGy.

The parameters of accelerator during irradiation were as follows:
- electron energy: 8.5 MeV;
- average beam current: 1 mA;
- average beam power: 7 kW;
- pulse duration: 4 μs;
- pulse repetition frequency: 300 Hz;
- scanning length: 600 mm.

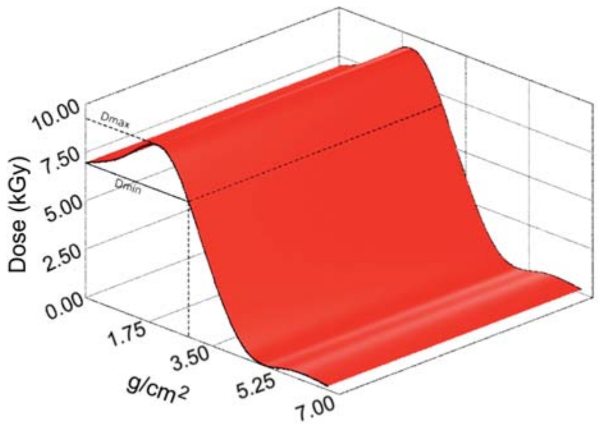

Fig. 4. Depth-dose distribution for one side irradiation.

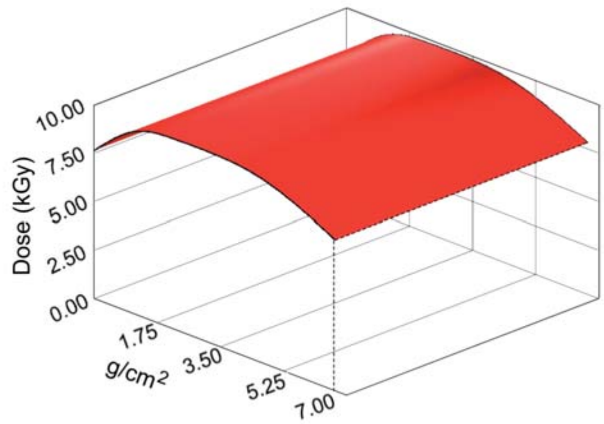

Fig. 5. Depth-dose distribution for two side irradiation.

Results

The theoretical data of depth-dose distribution for 10 MeV electrons reports that for water irradiation (density 1 g/cm^3) the dose reaches a maximum at a depth of 3.1 cm (3.1 g/cm^2) and the dose is equal to the entrance dose at a depth of 3.9 cm [3]. The process of food irradiation must be kept to provide the dose in the range from maximum D_{max} to minimum dose D_{min} characterized by the dose uniformity ratio defined as $U = D_{max}/D_{min}$. The values of U in the process of electron beam food irradiation required in Directive of the European Parliament should not exceed 3 [1]. It is important for the process to determine the regions of a minimum and maximum dose in irradiated products.

The results of the experiments show the dose distribution in food products irradiated with electrons of energy 8.5–9 MeV from the accelerator Elektronika 10-10. The dose distribution during one side irradiation is show in Fig. 4.

From the result for the INCT accelerator the maximum depth dose D_{max} = 9.1 kGy is achieved for F = 2.3 g/cm^2, and the dose is equal to the surface dose for F = 2.8 g/cm^2. The optimal conditions from the economical point of view for the irradiation process are achieved when the minimum dose is equal to the surface dose. In our condition $D_{min} = D_{surface}$ = 7 kGy. The ratio D_{max}/D_{min} = 1.3. In this region the uniformity index is constant. The maximum acceptable uniformity ratio U_{max} = 3 for the food irradiation process, when the exit dose is equal one third of the maximum dose is for the F = 3.8 g/cm^2. Basing on dose distribution for one side irradiation, the conditions for two side irradiation can be estimated to provide uniform irradiation dose in the whole volume of product and to not exceed approved limit of maximum dose for food irradiation. For this calculations the basis parameter is F for $D_{max}/2$ from one side irradiation curve. In our experiments it was F = 3.4 g/cm^2. The depth-dose distribution for the two side process will be optimal if the F = 6.8 g/cm^2.

The dose distribution for two side irradiation is shown in Fig. 5.

The maximum dose is D_{max} = 9.8 kGy and the ratio D_{max}/D_{min} = 1.3. For two side irradiation process the maximum F value was 7.6. Based on this results the optimal condition for irradiation process can be determine for any type of food product.

Conclusion

Irradiated food products should not receive the maximum radiation dose established by regulatory authorities in most countries. From the economical point of view, avoiding unnecessary high doses increases costs of the process. On the other hand, it must be assured that all points of an irradiated batch received at least the minimum dose. It is therefore important that the dose measurements should be as accurate as possible. Appropriate dose measure system helps to provide assurance that the radiation treatment is both effective and legally correct.

The method of dose measurement with dose reader CD-07 is easy, fast and reliable method. It enables to measure with high accuracy both dose and the energy of electrons. Its advantage is possibility of placement the dosimetric foil on desired level inside the product for depth-dose determination. In commercial irradiation process it is acceptable to reach the ratio D_{max}/D_{min} = 3. Based on the results obtained from the experiments it is possible to not exceed the ratio 1.3 which is the highest possible dose uniformity distribution during irradiation with high energy electrons beam.

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