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A METHOD FOR THE DETERMINING OF THE K FACTOR IN ELECTRON BEAM ACCELERATOR

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ABSTRACT

The absorbed dose received by an irradiated product depends on the following factors: the characteristics of the beam, which consist of electron energy, average beam current, scan width and scan uniformity; the conveyor speed; the product composition and density; the composition, density and thickness of material; and the distance of output window to the product. The significant parameters controlled by the operator were the characteristics of the beam and the conveyor speed. As this accelerator has been used for various applications in radiation processing, product surface doses must be set and utilized through operational qualification such as beam energy, beam current, scan width and conveyor speed. In this work, we have described a simple method for determining the K factor for the 3 MeV facility. The qualification was carried out using Alanine dosimeters and the calculations were evaluated according to ISO/ASTM 51649 and ISO 11137-3. The relative uncertainty of the measurements was estimated to be 4.20-7.10 %.

ABSTRAK

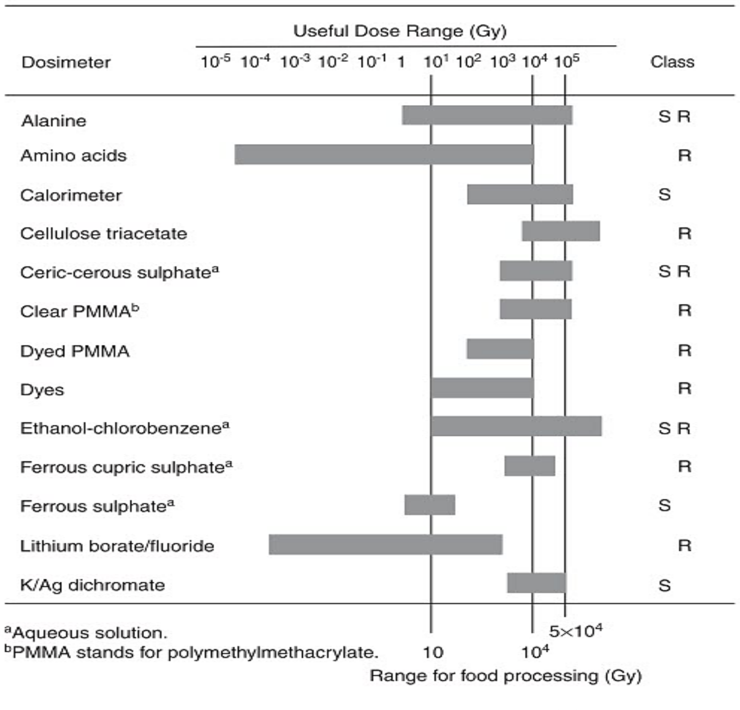
Dos yang diserap yang diterima oleh produk yang disinari bergantung kepada faktor-faktor berikut: ciri-ciri rasuk, yang terdiri daripada tenaga elektron, arus rasuk purata, lebar imbasan dan keseragaman imbasan; kelajuan penghantar; komposisi dan ketumpatan produk; komposisi, ketumpatan dan ketebalan bahan; dan jarak tetingkap keluaran ke produk. Parameter penting yang dikawal oleh pengendali ialah ciri-ciri rasuk dan kelajuan penghantar. Memandangkan pemecut ini telah digunakan untuk pelbagai aplikasi dalam pemprosesan sinaran, dos permukaan produk mesti ditetapkan dan digunakan melalui kelayakan operasi seperti tenaga rasuk, arus rasuk, lebar imbasan dan kelajuan penghantar. Dalam kerja ini, kami telah menerangkan kaedah mudah untuk menentukan faktor K untuk kemudahan 3 MeV. Kelayakan telah dijalankan menggunakan dosimeter Alanine dan pengiraan telah dinilai mengikut ISO/ASTM 51649 dan ISO 11137-3. Ketidakpastian relatif pengukuran dianggarkan 4.20-7.10%.

Keywords: absorbed dose, accelerator, Alanine dosimeters

INTRODUCTION

The first high-energy electron beam in Malaysia was installed in the Malaysian Nuclear Agency in 1991. The EPS-3000, prototype machine developed by Nissin High Voltage Japan. This facility was born from the need for research in the field of radiation processing. EPS-3000 generated high voltage by using the Cockcroft Walton multiplier circuit. It can be operated at 0.5-3 MeV, 1-30 mA and can deliver a maximum beam power of 90 kW. The conveyor speed is adjustable from 1 to 20 m/min. Samples to be processed are put in a stainless-steel trolley of 120 cm length, 60 cm width and 10 cm depth, and conveyed perpendicularly to the scan direction.

A dosimeter is a device, instrument or system that measures or evaluates, either directly or indirectly, the physical units specific to dosimetry. The most usual dosimeters and their dose range are as shown in Figure 1 (1). Dosimeters to be used for calibration and monitoring in the electron beam processing are more restricted than gamma because of the relatively short-range penetration of electrons and high dose rates. Among solid-state dosimeters, the alanine dosimeters have found a wide acceptance for measuring doses in radiation fields. Alanine dosimetry systems are well-established and convenient for reference, transfer and routine dosimetry. The accuracy and reproducibility of the measurement assure a low uncertainty on absorbed dose determination (2,3). Alanine dosimeters have not yet been used as a reference in EPS-3000 electron beams since they have been installed. There is a lack of study of EPS-3000 electron beams for the dose range between 1 kGy and 10 kGy at the uncertainty level required for sanitary purposes. The advantages of alanine over Fricke dosimeters are that Fricke dosimeters are bulky and difficult to handle. Alanine also could be used as a reference check of the dosimetry before sanitary and phytosanitary use. Alanine dose meters can also be placed in various positions on the food or fruits for dose mapping study.



R-routine; S- reference standard (1)

Figure 1. Various types of dosimeters and their useful dose range for radiation processing

The absorbed dose sometimes referred to as 'dose', is the amount of energy absorbed per unit mass of irradiated matter at a point in the region of interest. Absorbed dose of a product depends on average beam current, beam width, conveying speed and beam energy. Measurement of dose as a function of these parameters constitutes effectively a calibration of the electron beam facility (4). The dose at the surface as a function of conveyor speed, beam current and scan width can be estimated using Equation 1.

$$D_{surf}\left(kGy\right)=6000\times\frac{1\left(mA\right)*\left(S/p\right)\left(MeV\cdot cm^2/g\right)}{Conveyor\ speed\left(m/\min\right)*Scan\ Width\left(mm\right)} \qquad (1)$$

where

(S/ ρ) (MeV.cm^2/g): collision stopping power for Water (S/ ρ) (MeV.cm^2/g) = 1.968 at 10 MeV (NIST database) or

$$D_{surf}\left(kGy\right)=\left(K*I\right)/\left(V*Wb\right) \qquad (2)$$

where:

I = Beam current (mA),

V = Conveyor speed (m/min),

Wb = Beam width (m),

K = Slope of the straight-line relationship

From Equation 2, the dose at the surface product irradiated in an electron beam facility is proportional to the slope of the straight-line relationship (K), average beam current (I), and inversely proportional to conveyor speed (V) for a given electron beam energy and the beam width (Wb) is usually kept constant. To determine the relationship, the dose shall be measured at a specific location and for a specific irradiation geometry using several selected parameters sets of beam current, conveyor speed and beam width to cover the operating range of the facility.

METHODOLOGY

The experiments were performed on a 3 MeV Electron Beam (EB) Machine. The electron beam scan width depends on the accelerator specification (exit window length) of certain accelerator construction. The width of the scanned electron beam forms an irradiation zone in the direction of the beam sweeping which is located perpendicularly to the product movement (5). The beam scan width was set at 1200 mm. As the standard irradiation, the distance between the conveyor surface and the accelerator window was set at 200 mm (Figure 2). Figure 3 shows the complete setup assembly used for the experiments. Polystyrene plates were 8.0 x 10.0 x 1.0 mm and 1.05 g/cm3 in density. For each experiment, 4 pieces of polystyrene plates were used.

AERIAL commercial alanine dosimeters with a nominal diameter of 5.0 mm and 2.0 mm thickness were used in this work. The four holes were drilled to place the alanine dosimeter on the second plates. Four alanine pellets were placed into four small holes made in a polystyrene plate holder. This allowed for easy manipulation (mechanical support) and ensures a continuity of matter at the edges of the pellets for lateral electron equilibrium (6). The assembly of dosimeters was placed at the centre of the beam. In this study, the alanine dosimeter was read with an alanine reader operated at AERIAL (France).

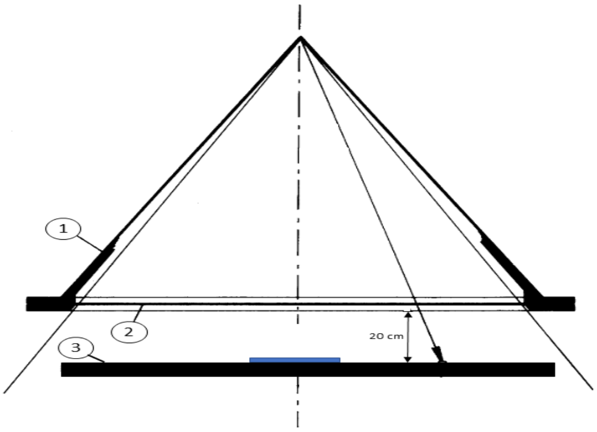


Figure 2. Schematic view of the scanner, the conveyor, and the irradiation position. (1) Scanner, (2) window, (3) conveyor

(a) (b) ©

Figure 3. The setup for absorbed dose tests (a) location of the alanine, (b) the assembly of polystyrene and alanine and (c) placement of the assembly during the irradiation.

The variables for this study were energy, current and conveyor speed. The alanines were then exposed to 3 MeV electron beam irradiation. There were nine sets of experimental combinations for each condition as shown in the table. An appropriate array was selected to analyse the effects of these variables on the dose at the surface.

Table 1. Array design of experiments

Experimental No.	Energy (MeV)	Current (mA)	Conveyor speed (m/min)
1	3	2	1.88
2	3	2	9.40
3	3	2	18.80
4	3	4	1.88
5	3	4	9.40
6	3	4	18.80
7	3	10	1.88
8	3	20	9.40
9	3	20	18.80

RESULTS AND DISCUSSION

The dose for various currents and conveyor speeds for alanine dosimeter were as shown in Table 2. From the results, the dose achieved was in the range of 1.00 kGy to 52.9 kGy. Figure 3 shows the relationship between dose at the surface of the product and current/speed. Generally, the dose increased linearly with the current/speed. As the current/speed was increased, the dose at the surface of the product also increased. From the linear plot of Figure 3, the K factor (equation 2) was determined. This meant that the dose at the surface of a product could be estimated by multiplying the I/V value (in mA.min/m) by approximately 10.

The consistency of the applied dose had been checked as multiple couples of current and speed could be chosen to set up a process. Table 3 shows the deviation of the dose for the same current/speed ratio of the doses with the dose estimated by using the K factor. The results showed a good match between the two measured doses, even though at low current or high speed, the deviation was significant in considering uncertainties of alanine measurements. The origin of this discrepancy may have come from speed instabilities.

Table 2. Averages dose for various currents and conveyor speeds in kGy

Experimental No.	Energy (MeV)	Current (mA)	Conveyor speed (m/min)	Current /Speed (mA.min/m)	Dose (kGy)	Stand. Dev. ±
1	3	2	1.88	1.06	10.75	0.33
2	3	2	9.40	0.21	2.19	0.07
3	3	2	18.80	0.11	1.00	0.03
4	3	4	1.88	2.13	21.10	0.60
5	3	4	9.40	0.43	4.53	0.14
6	3	4	18.80	0.21	2.04	0.06
7	3	10	1.88	5.32	52.90	1.60
8	3	20	9.40	2.13	22.00	0.70
9	3	20	18.80	1.06	10.36	0.32

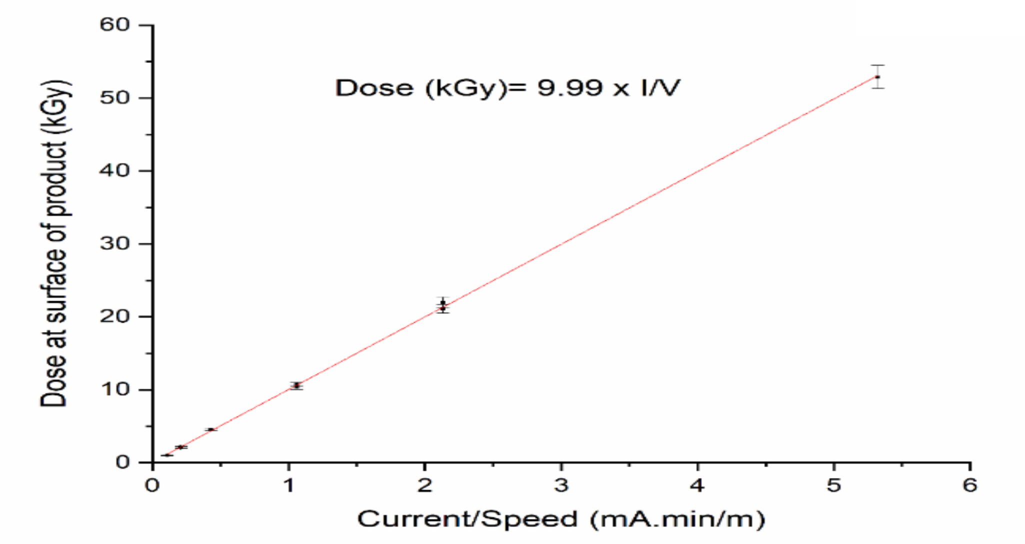


Figure 3. Dose linearity with current/speed using alanine dosimeter

Table 3. Dose measurements for same ratio of current/speed

Current/Speed (mA.min/m)	Dose 1 (kGy)	Dose 2 (kGy)	Dose estimated by multiplying the I/V value	Deviation (%)
0.21	2.19	2.04	2.1	7.10
1.06	10.75	10.36	10.6	3.70
2.13	21.10	22.00	21.3	4.20

CONCLUSIONS

The relationship in Equation 2 established the dose measurements with different combinations of the parameters I and V. This relationship shows that it is a straight line passing through (0,0) and proves that at a given beam energy, the dose can be selected by appropriate choice of these parameters. The dose rises with an increase in current/speed. The relative uncertainty of the measurements was estimated to be 4.20-7.10 %. The study demonstrated that the alanine dosimeter is superior compared to the Fricke due to its ease of handling and non-destructive read-out technique. The dosimeter is also suitable for dose calibration and phytosanitary applications.

Further studies are needed to verify the dose measurement with simulation studies such as Monte Carlo simulation or Particle and Heavy Ion Transport Code System (PHITS) during irradiation.

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