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A DOSIMETRIC SURVEY OF THE DC1500/25/04 ELECTRON BEAM PLANT INSTALLED AT IPEN-CNEN/SP

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ABSTRACT

In this work we describe a dosimetric survey of the DC1500/25/04 electron beam accelerator installed in the Intense Sources of Radiation Laboratory at IPEN/CNEN-SP. As this accelerator has been used for innumerable applications in radiation processing, product surface and internal doses must be targeted and controlled via operational qualification such as beam energy, beam current, scan width and conveyor speed. The qualification of the accelerator was carried out in order to observe the current performances of the irradiation plant using Alanine (ESR) and CTA (UV Spectrophotometry) dosimeters. Energy (Electron penetration in material) calculations, scanning width/length, homogeneity and irradiation uniformity were evaluated according to ISO/ASTM 51649 and ISO11137-3, as well as process uncertainty establishment.

1. INTRODUCTION

Since it was installed in 1978 at the Intense Sources of Radiation Laboratory (IPEN/CNEN-SP), the JOB 188 type electron beam accelerator from IBA Industrial [1] has been used for innumerable applications [2-4], such as sterilization of medical, pharmaceutical and biological products, treatment of industrial and domestic effluents and sludge, preservation and disinfestations of foods and agricultural products, lignocellulosic material irradiation as a pre-treatment to produce ethanol bio-fuel, decontamination of pesticide packing, solid residues remediation, organic compounds removal from wastewater, treatment of effluent from petroleum production units, crosslinking of foams, wires and electric cables, composite and nanocomposite materials and carbon fibers irradiation, irradiated grafting ion-exchange membranes for fuel cells application, natural polymers and multilayer packages irradiation, and biodegradable blends production.

For all those applications, product surface dose and internal dose must be targeted and controlled via the processing parameters as beam energy, beam current, scan width, conveyor speed. Recently, a high precision and speed-controlled conveyor was built so as to increase the product velocity control thus, achieving better uniformity during irradiations. With the aim of implement a Secondary Standard Dosimetry Laboratory, some important technical aspects have been evaluated. One of them is the characterization of the Electron Beam plant in terms of Operational Qualification (OQ) according to ISO/ASTM 51649 and ISO11137-3 [2,5], described in this work.

2. MATERIALS AND METHODS

As the electron energy spectrum, the average beam current and the conveyor speed are the most important characteristics that influence the absorbed dose, several duties were performed to characterize the Electron Beam plant: measurement of EBeam energy with stack technique in Polystyrene (PS), depth dose distribution in PS, wood, carton and cork, effect of aluminum scattering foil on dose distribution, linearity test Surface Dose vs Current/Speed, linearity test Surface Dose vs number of pass, scan length and scan uniformity of 1.5 MeV Ebeam, surface dose uniformity in travel direction (conveyor direction).

Dosimetry for the studies listed above was realized by using mainly optical and ESR dosimetry systems. The ESR spectrometer, a MS400 (Magnettech, Berlin) [6] equipped with the AerEDE dosimetry software from Aerial France, is a free radical measurement tool which is used to determine absorbed dose with Alanine pellets. Alanine pellets were provided by Aerial, France. Those pellets of 4mm diameter and 2.2mm thickness contain 93% alanine and 7% binder. The Spectrophotometer (554nm)/GEX and Spectrophotometer (280nm)/CTA dosimetry systems were used to measure surface dose with single chip dosimeters or to determine dose profiles with strips of CTA [7-9].

Dynamitron DC1500/25/04 type electron beam accelerator (EBA-model JOB 188) was manufactured by IBA Industrial (Radiation Dynamics, Inc.) and installed in the Intense Sources of Radiation Laboratory at IPEN/CNEN-SP in 1978. The technical specifications of the EBA are summarized in Table 1.

Table 1 – Technical specifications of electron beam accelerator model JOB 188, dynamitron DC1500/25/04 type, manufactured by IBA Industrial.

Parameter	Value
Energy	0.5 to 1.5MeV
Beam current	0.3 to 25.0mA
Beam width	60 to 120cm
Beam length on window surface	2.54cm
Frequency	100Hz

3. RESULTS

3.1. Energy of electron beam and depth-dose distributions

For electron energies of few MeV it is well established that depth-dose measurements with polystyrene plates can be used to determine the electron beam energy. Both electron beam energy and depth-dose evaluation in homogeneous materials were performed using the stack procedure, where plates of reference materials were arranged one on top of another, placed in-between with dosimeter films of CTA.

The results obtained with this technique for plates of polystyrene (PS), density 1.025, 0.100g/cm² per plate, target energy of 1.5MeV and the distance from window of 17 cm are presented in Figure 1. It can be seen that the practical electron range (Rp) is 0.6g/cm². The ISO/ASTM 51649 standard gives a relation formula between Rp and electron energy (E) in polystyrene in the range between 0.3 and 2.0MeV as below:

$$E = 1.972 \text{ x } Rp + 0.245 \qquad (1)$$

For Rp = 0.6g/cm², one can calculate E = 1.43MeV. The same measurements were done for wood, density 0.78, 0.131g/cm² per plate; carton, plates density 0.60, 0.108g/cm² per 2 plates and cork plates density 0.345, 0.088g/cm² per plate. Placed on the same graph (Figure 2), all depth dose curves exhibit similar shape and similar practical electron range of about 0.6g/cm².

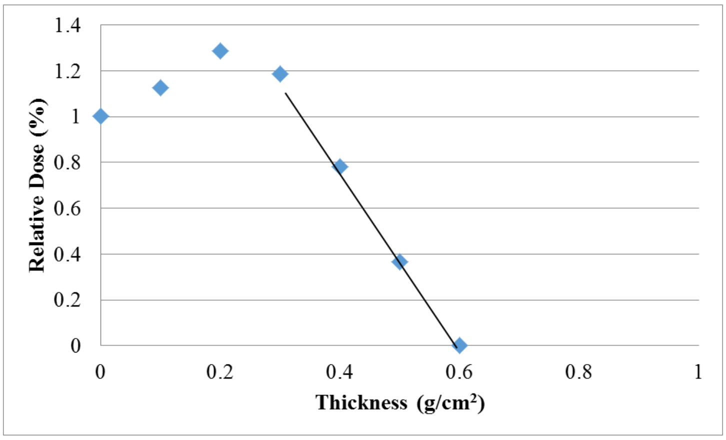


Figure 1: Depth dose curve in PS at target energy of 1.5MeV and the distance from window 17cm (CTA dosimeters).

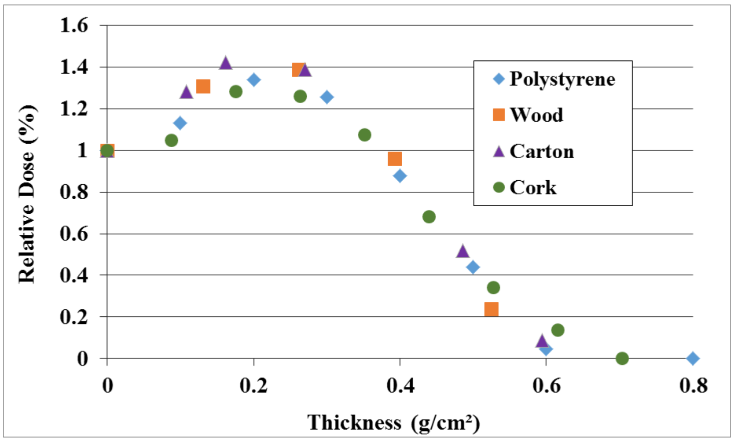


Figure 2: Depth dose curve in PS, wood, carton and cork at target energy of 1.5MeV and the distance from window 17cm (CTA dosimeters).

3.2. Linearity test Surface Dose vs Current/Speed

As part of the qualification of the electron beam plant, the relation between the surface dose at the center of the beam and the average beam current/conveyor speed ratio was studied for a 1.5MeV electron energy positioning a PMMA plate with locations for 4 alanine pellets 17cm distant from the window. Current and conveyor speeds used are given in the Table 2 below.

Table 2 - Current and conveyor speeds used in the linearity test. Expected doses are displayed where X is the dose in kGy delivered for current/speed = 1mA.min/m.

	1mA	3mA	6mA	10mA	15mA
3 m/min	X/3 kGy	X kGy	2X kGy	(10/3)X kGy	5X kGy
6 m/min	X/6 kGy	X/2 kGy	X kGy	(10/6)X kGy	2.5X kGy
10 m/min	X/10 kGy	3X/10 kGy	6X/10 kGy	X kGy	1.5X kGy

Figures 3 and 4 depicted the results obtained for the surface dose versus current/speed and its residuals, respectively.

A linear relationship between surface dose derived from Alanine dosimeter readings and the current/Speed ratio has been demonstrated in equation 2.

$$\text{Dose surface (kGy)} = 7.0 \times \text{Current/ Speed (mA.min/m)} \quad (2)$$

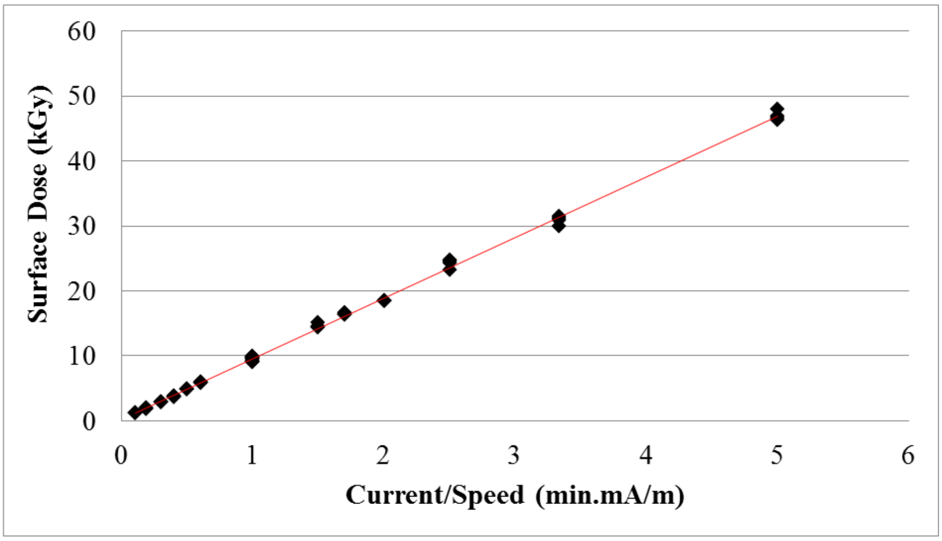


Figure 3: Surface dose (kGy) at 17cm from window (Alanine) according to current/speed ratio in mA.min/m.

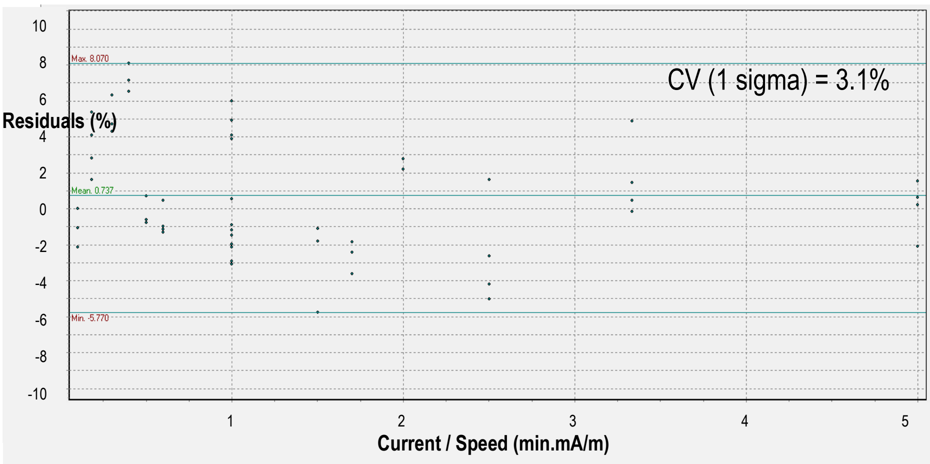


Figure 4: Residual plot (%) according to current/speed ratio in mA.min/m.

The residual plot in Figure 4 shows the spread of the data around this linear model and reveals an overall standard deviation (1sigma) of 3.1%. This value can be used as the irradiation uncertainty on the surface dose to a product when measured with Alanine dosimeters. It represents the combined uncertainty of the irradiation process and the reproducibility of alanine dose measurements. Thus, the relationship can be written as follows:

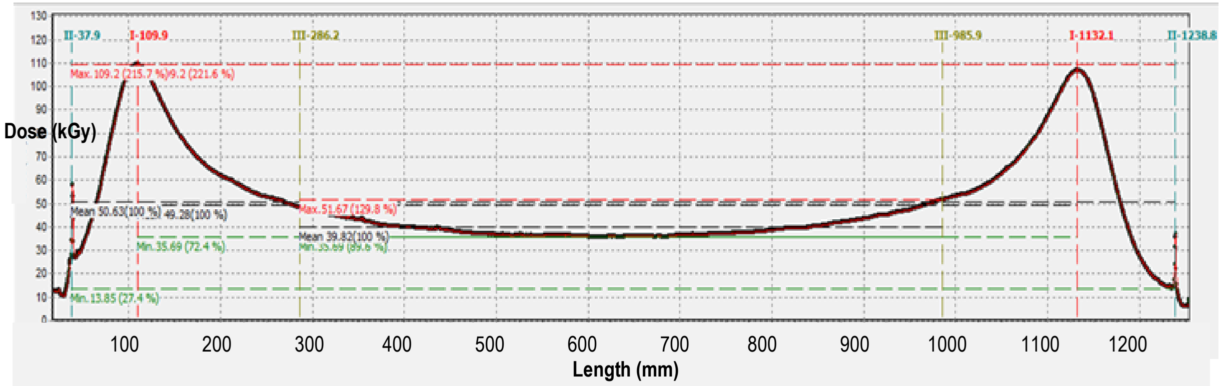
$$\text{Dose surface (kGy)} = 7.0 \pm 0.4\ (k = 2) \times \text{Current/ Speed (mA.min/m)} \qquad (3)$$

3.3. Scan width, spot size (length) and scan uniformity

The EBeam shape coming out of the scanner can be characterized through three relevant parameters: (a) scan width; (b) scan homogeneity and (c) centering of the electron beam. These parameters were evaluated for 1.5MeV energy beam through a CTA dosimeter strip of 1.3m length placed on top of a wood bar, 1.3m length, positioned parallel to the scanning horn on the tray. The distance from window was 17cm and scanning width of 1m. The dosimeter was readout with a Dos'ASAP equipment (Aerial, France) (Figure 5) which allows measuring the strip in a continuous mode. All parameters of interest have been derived from the recorded dose profile provided by Dos'ASAP as follows in Figure 6.

Figure 5: Dos'ASAP equipment (Aerial) measuring the strip in a continuous mode.

As expected, the scan width was measured to be about 1.02m long (distance between red cursors). Irradiation uniformity across the tray (70cm) of the conveyor (CV% of the yellow cursor zone) is evaluated to be -10% to +30% from the average delivered dose. The middle of the EBeam is out of center of scanner by about 17mm towards the left hand side. Those

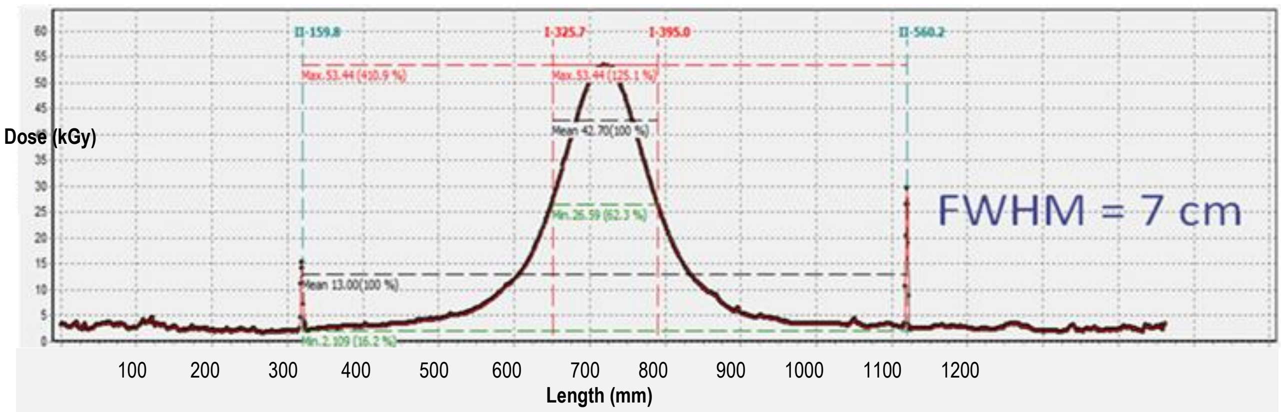


Label	ROI Mode	ROI-L (mm)	ROI-R (mm)	Centre (mm)	Width (mm)	Mean dose (kGy)	Min dose (kGy)	Max dose (kGy)	Min at (mm)	Max at (mm)	UCTY (kGy)	Min UCTY (kGy)	Max UCTY (kGy)
Ebeam	Manual	109.9	1132.1	621.0	1022.2	49.28	35.69	109.2	604.3	109.9	5.01	4.00	9.81
Pos. mark	Manual	37.9	1238.8	638.4	1200.9	50.63	13.85	109.2	1235.3	108.0			9.81
	Manual	286.2	985.9	636.0	699.7	39.82	35.69	51.67	604.3	985.9	4.28	4.00	5.15
Tolerance L				20 mm	950mm								
Tolerance H				20 mm	1050mm								

Figure 6: Beam shape (dose profile) along the scanning.

results show that the products to be irradiated must be placed in the center of the tray where the surface dose is the most homogeneous. For products larger than 35cm, one can expect a surface dose variation higher than +/- 5% (minimum to maximum).

For the spot size (Beam length) test, the wood bar with CTA strip has been irradiated for several seconds in static mode across the beam. The result is shown in Figure 7 below. At a distance of 17cm from the window, where the CTA strip has been placed, the beam length at half maximum (FWHM) has been evaluated as FWHM = 7.0cm.



Label	ROI Mode	ROI-L (mm)	ROI-R (mm)	Centre (mm)	Width (mm)	Mean dose (kGy)	Min dose (kGy)	Max dose (kGy)	Min at (mm)	Max at (mm)	UCTY (kGy)	Min UCTY (kGy)	Max UCTY (kGy)
	Manual	325.7	395.0	360.4	69.3	42.70	26.59	53.44	395.0	359.4	4.51	3.52	5.29
	Manual	159.8	560.2	360.0	400.4	13.00	21.09	53.44	162.6	359.4			5.29

Figure 7: Surface dose profile in travel direction.

3.4. Linearity test Surface Dose vs Number of pass

This test was performed by irradiating a PMMA plate with locations for 4 alanine pellets with 1.5MeV target energy, 17cm distance from window and scanning width of 1m. The results obtained presented in Table 3 and Figure 8 confirm that multiple pass under the EBeam with proportionally less current will conduct to the same surface dose.

For this test, the tolerated dose limits indicated with red lines are defined as the average of the measured doses ± 6.2% (see 3.2).

This graph shows that all measured data points are positioned between the two limits corresponding to the uncertainty of the EBeam process and alanine dosimeter reproducibility. The maximum acceptable should then be 32.7 kGy and the minimum acceptable 29.0 kGy.

Table 3: Current and conveyor speeds used in the linearity test, as well as the alanine readouts.

Speed (m/min)	Current (mA)	Number pass	Surface Dose (kGy)
3	12.5	1	31.6 +/- 0.4
3	6.25	2	29.7 +/- 0.8
3	4.16	3	31.3 +/- 0.6
3	3.13	4	30.4 +/- 0.4
6	12.5	2	31.4 +/- 0.5
6	8.3	3	30.4 +/- 0.5
6	6.25	4	30.6 +/- 0.6

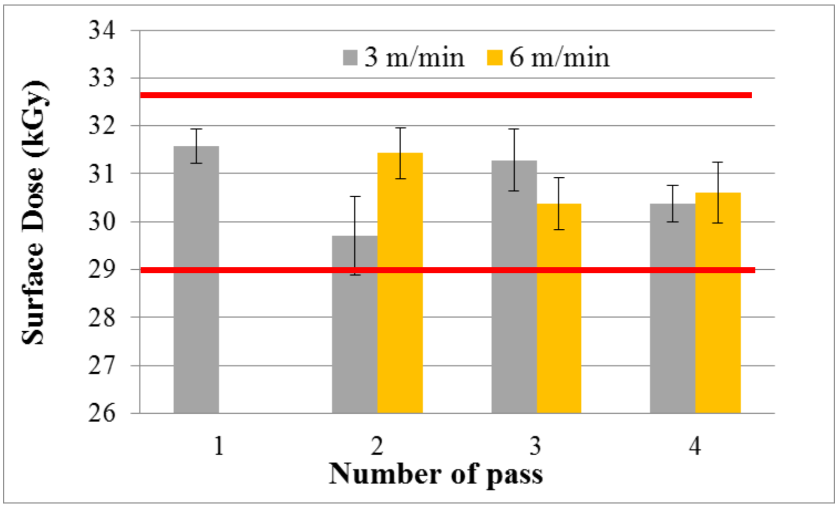


Figure 8: Linearity Dose vs number of pass

4. CONCLUSIONS

The work presented reflects the qualification tests performed in DC1500/25/04 electron beam accelerator at IPEN-CNEN/SP during IAEA expert mission with the aim of qualify implement a Secondary Standard Dosimetry Laboratory for Brazil and South America. Based on the calibrated ESR/Alanine dosimetry system, qualified EBeam plant, IPEN now benefits from the necessary tools to provide accredited dose measurements to its customers. The accreditation of this laboratory to the dose measurement between 10Gy and 50kGy with ESR/Alanine system for high energy EBeams (1.5MeV) following ISO 17025 is under way.

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