ELECTRON BEAM PARAMETERS DETERMINATION BY MEANS OF CELLULOSE TRIACETATE DOSIMETRIC FILMS

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ABSTRACT

Electron beam parameters can be determined by different ways and one of the most simplest is by using folded dosimetric films in stack form. Energy dissipation curves were determined for a 1.5 MeV electron beam accelerator at the Industrial and Engineering Applications Coordination, Instituto de Pesquisas Energéticas e Nucleares/SP. When electrons of an energy E, penetrate in a matter of a given thickness ($g.cm^{-2}$) and dissipate their energy through that thickness, dose versus material depth distributions can be used for EB parameters determination. Different electron energies were used in the experiment ranging from 0.5 MeV to 1.5 MeV. Since the electron beam is scattered by the air after traversing the titanium (Ti) window and before impinging the stack of films, adequate distance between the Ti window and the stack was maintained. The evaluation of the absorbed energy, converted to dissipation energy, was made by the measurement of optical density change of the films in the UV absorption region (280 nm) by means of a calibration curve made in ^{60}Co gamma rays device. The results were compared with the calculated values by using the EDMULT computational code.

INTRODUCTION

Electron beam (EB) facilities are of great importance in many fields of materials processing in industrial scale. This technology is in continuous growing in Brazil and is applied to different purposes: research and development as well as for commercial services. Some of the applications of EB facilities compete with other technologies using non radiative media for materials bulk changes. This competition is mainly based on the increase of costs and spending of time in the old type treatments.

Accelerated electron beams are being used at IPEN-CNEN/SP in research and development as well as in commercial applications. Two accelerators are installed with the same maximum energy, 1.5 MeV. The difference between these accelerators is that the maximum current output of each one is 25 mA and 65 mA. Due to this fact a wide range of dose-rates can be achieved ranging from 1.2 to 651 kGy/s. There are several research projects under development such as polimerization, varnishes curing, sewage water treatment, flue gas treatment, hydrogel reticulation and many others. Cables irradiation is part of the commercial application of both accelerators.

When the use of an accelerator is so diversified and when new materials are studied for industrial, medical and public health applications one of the technical problem is to achieve uniform distribution of energy deposition in the irradiated medium. It is possible to determine the distribution of the electron energy dissipation in finction of depth. This can be made by means of calorimetry or ionization chambers[1] (extrapolation type) although there are problems of poor lateral resolution and corrections for cavity theory as shown by Burlin[2].

Measurements of monoenergetic electrons can be made by means of depth-dose distributions in different materials.

In this study, energy dissipation of electrons in three layer materials was considered.

The penetration of the electron beam increases with the accelerator voltage so three energies were considered: 0.6 , 0.8 and 1.5 MeV. Accelerated electron beam passes first through the titanium (Ti) window then across an air layer and finally penetrates into the material layer that in the present work is represented by tricellulose acetate (CTA). After achieving a prefixed dose, the films were processed by means of spectrophotometric analysis and depth-dose curves were obtained. The results were compared with those calculated values by using a computational code, EDMULT, developed by Tabata et all[3].

The EDMULT code was developed to calculate the energy deposition of electrons normally incident on materials placed under the beam.

There is an equation developed by Seltzer [4] that allows to verify if the initial energy of the electron beam is equal or different of the prefixed energy. It takes into consideration the depth values obtained in the depth-dose curves based on the experimental data.

EXPERIMENTAL

Film Dosimeters. Triacetate cellulose thin films used for energy dissipation curves evaluation were previously calibrated by using a ^{60}Co gamma source that was calibrated by means of Fricke dosimetry.

The evaluation of absorbed doses was made by the measurement of optical absorption change, before and after irradiation, taken at 280 nm by using a Hitashi 100-20 spectrophotometer. The films thicknesses were measured using a Peacock thickness gauge.

The electrons energy dissipation in CTA films can be measured by preparing CTA flat films stacks, 8 mm width and 5 cm length, with different number of slabs, depending on the electrons energy. As higher is the energy of the electron beam, i.e. accelerator voltage, thicker is the CTA film stack. The total thickness of the stack can be determined by means of material density and accelerator parameters. In the present case the thickness of the stack was calculated as follows:

$$HVD(\mu A) = 25.6 + 187.8 \, . \, \rho(g.cm^{-3}) \, . \, x(cm)$$

where ρ is the density of the CTA film, x is the thickness of the CTA layer and HVD is the value of the current in the high voltage divisor. The constants values 25.6 and 187.8 depends on the irradiation way. They are used when a one side irradiation is to be made, i.e. the electron range is equal to the total thickness of the material, so the absorbed dose values are the same at both entrance and exit of the beam. These constants change to 19 and 79.7 respectively if a two side irradiation is adopted due to material thickness and accelerator parameters.

The thickness of the film stacks, from 0.2 cm to 0.6 cm, used in this work was exagereted in order to allow all the electrons to be absorbed into the considered material since one side irradiation was used.

The films in the CTA stack must be very tight each other to avoid dose evaluation discrepancies due to some discontinuity provoked by maladjustment. The stacks were fixed on lucite plates and for each energy, three CTA stacks were irradiated at the same time.

Operation Behaviour. Figure 1 illustrates the experimental set up of the arrangement used in this work.

The accelerator generates monoenergetic electrons by means of a rectified transformer type manufacturated by Radiation Dynamics Inc. The electron beam has a normal incidence on a medium placed on the conveyer. The conveyer traveled forth and back under the irradiation window perpendicular to the direction of the scanned electron beam. Conveyer velocity was fixed as 3.36 $m.min^{-1}$. Accelerator current was fixed as 1 mA. The electron beam had a scanning width of 60 cm on the substrate. The substrate used was a lucite plate that can

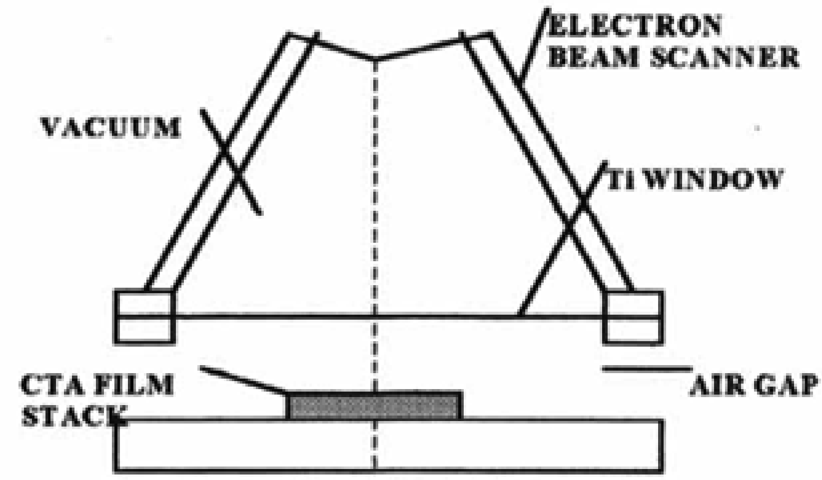

Figure 1 - Experimental Set Up Used for Energy Dissipation Measurement of the Scanned Electron Beam Incident on CTA Films Stacks Placed on the Dynamic Conveyer.

absorb all the electrons that eventually passed through the CTA film stack. This substrate avoids the backscattering effect which subsequently could give rise to higher electron interaction with the irradiated material which gives rise to higher dose values.

All the values used in experiments and those that are fixed are shown in TABLE 1.

TABLE 1. Parameters Used During Irradiation of CTA Films Stacks in an Accelerated Electron Beam.

Parameters	Medium Ti	 Air	 CTA
Thickness (cm)	0.004	9.1 ; 21	0.0125
Density ($g.cm^{-3}$)	4.76	0.0013	1.30
Z_{eff} (effective atomic number)	22	7.2	6.7
A_{eff} (effective atomic weight)	47.9	14.4	12.73

TABLE 2 shows the dose rates achieved for extreme values of electrons energy and beam current, for both accelerator models.

EDMULT code. The EDMULT code, EDP87, version 3.02, is a deterministic method that utilizes an algorithm developed by Kobetich and Katz[5]. It runs in MS DOS with a 80x87 math coprocessor. The programming language used in this code is Fortran 77 so care must be taken when introducing the values of energy, thicknesses of air and CTA, the effective atomic numbers and atomic weights and the value of a choosen thickness increment.

TABLE 2. Dose Rates Achieved When Extreme Electrons Energy and Beam Current are Applied in Different Accelerators Models.

RDI Model	E(MeV)		I(mA)		D(kGy. s^{-1})	
	min	max	min	max	min	max
E00-10210	0.50	1.5	0.3	25	1.2	301.4
DPC-200	0.75	1.5	0.3	65	1.2	651.1

The message in EDMULT code used to introduce all those values is shown below:

1 E (MeV) T_{air} ($g.cm^{-2}$) T_{CTA} ($g.cm^{-2}$) ΔT
Z_{eff}(Ti) A_{eff} (Ti)
Z_{eff}(air) A_{eff} (air)
Z_{eff}(CTA) A_{eff} (CTA)
9

After running the program, the output data can be recuperated in order to plot the curves in some choosen Microsoft programme.

Energy Calculation. Seltzer[4], in his empirical equation, based on experimental data, showed that it can be used for estimation of the electron beam energy, by using two parameters: the 50% electrons range, R_{50}, also known as half-value depth, and the extrapolated range, R_{ex}. He considers that the energy is equal to an exponential function as:

$$E(MeV) = e^{x} \quad (1)$$

where x is given by,

$$x = 0.918 + 0.8727\, y + 0.0332\, y^2 \quad (2)$$

and y is the natural logarithm of R_{50}, $y = \ln R_{50}$.

Equation (1) is also applied to calculate the energy using the R_{ex} value, changing the constants in equation (2) as follows:

$$x = 0.7532 + 0.8736\, y + 0.0316\, y^2 \quad (3)$$

and y is the natural logarithm of R_{ex}, $y = \ln R_{ex}$.

RESULTS AND DISCUSSION

Experimental and Calculated Values Comparison. When electrons of initial energy E, pass through the Ti window and are scattered in the air gap, they loose part of their energy. Consequently the energy of incident electrons impinging the first layer of the CTA film stack is a quite lower. TABLE 3 shows these values. It is possible to see that the air gap have some influence in energy reduction depending on the CTA film stacks distance from the Ti window.

The irradiation of materials by accelerated electrons is somewhat complex because it depends on different variables as the accelerator parameters, geometrical arrangements and involved materials. It can be observed that by increasing the energy, the electrons are less influenced by multiple scattering deflections as normally occurs in the low energy interval, for different air gaps.

TABLE 3. Dissipated Electrons Energies in Ti Window and Air Gap Before Impinging the CTA Film Stakcs. Values Calculated by the EDMULT Code.

E (MeV)	$d_{Ti\text{-}CTA}$ (cm)	$E^{(1)}$ (MeV)	$E^{(2)}$ (MeV)
0.6	9.1	0.0717	0.5283
	21.0	0.1180	0.4820
0.8	9.1	0.0584	0.7416
	21.0	0.0953	0.7047
1.5	9.1	0.0453	1.4547
	21.0	0.0725	1.4275

$E^{(1)}$ Dissipated energy in the Ti window and the air gap.
$E^{(2)}$ Energy of electrons penetrating the CTA film stack.

Calculated values of electron energy dissipation in CTA were obtained by using the EDMULT code. The values were plotted as Energy Dissipation ($MeV.cm^2.g^{1}.ele^{-1}$) vs. Depth ($g.\ cm^{-2}$) distributions. Experimental data plotted as Absorbed Dose (kGy) vs. Depth ($g.\ cm^{-2}$) were also obtained. The absorbed energy per unit area was integrated numerically over the whole irradiated area, and this integrated value (kGy) divided by number of electrons ($ele\ .\ cm^{-2}$) and multiplied by a unit conversion factor. This procedure gives the energy dissipation per electron ($MeV.cm^2.\ g^{-1}\ .\ ele^{-1}$).

The comparison was made by normalizing both calculated and experimental results of energy dissipation in CTA.

Figures 2, 3 and 4 illustrates the experimental values of energy dissipation obtained for electrons of initial energies 0.6; 0.8 and 1.5 MeV, in CTA films and plotted along with the EDMULT code calculated curves for the same experimental parameters. These results are concerned to an air gap of 21 cm. Figures 5,6 and 7 were plotted with results obtained for a narrower air gap, 9.1 cm.

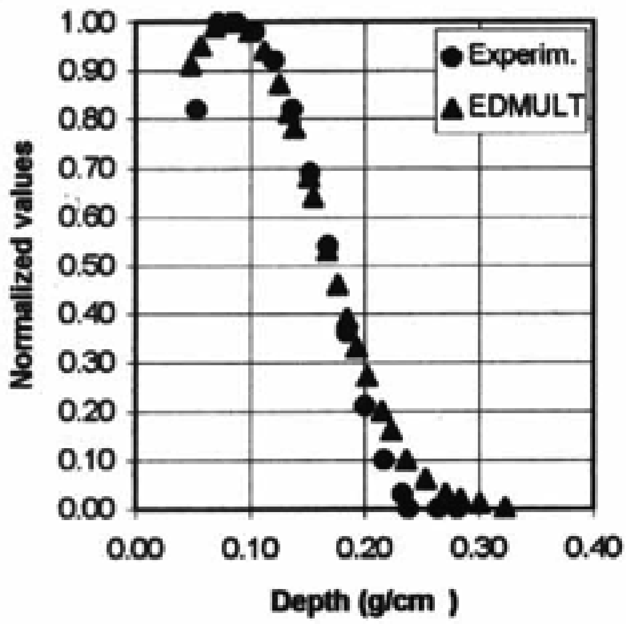

Figure 2. Comparison of Experimental and EDMULT Calculations for Energy Dissipation in CTA for 0.6 MeV Electrons and 21cm Air Gap.

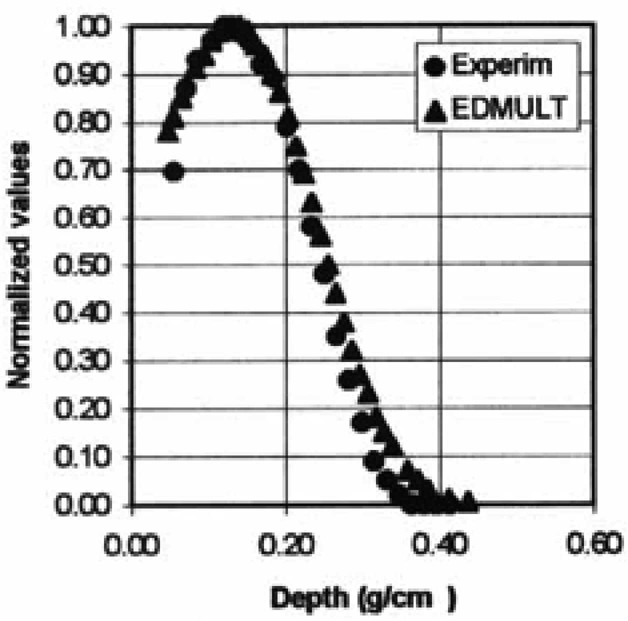

Figure 3. Comparison of Experimental and EDMULT Calculations for Energy Dissipation in CTA for 0.8 MeV Electrons and 21 cm Air Gap.

It can be seen that experimental and EDMULT energy dissipation curves, as a function of depth in CTA, are similar except at the final depth interval, for an air gap of 21 cm, where differences are more pronounced. This fact was also observed by other authors[6,7] when policarbonates films are used for an air gap of 19 cm. This is not observed for higher density materials as aluminium, titanium or antimonium[8] for a narrower air gap.

The maximum values occur within the CTA film stack and is closer to the electrons entrance surface for lower electrons energy. The dose-depth distribution is not so uniform due to deflections of the electrons in the CTA film stack.

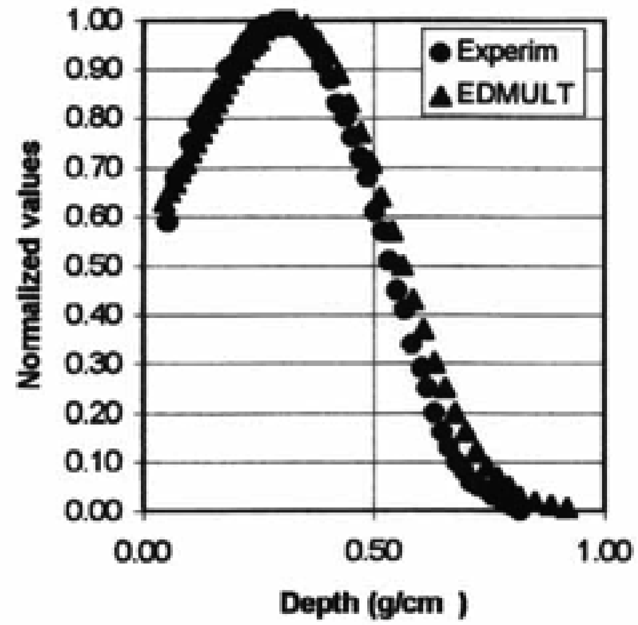

Figure 4. Comparison of Experimental and EDMULT Calculations for Energy Dissipation in CTA for 1.5 MeV Electrons and 21 cm Air Gap.

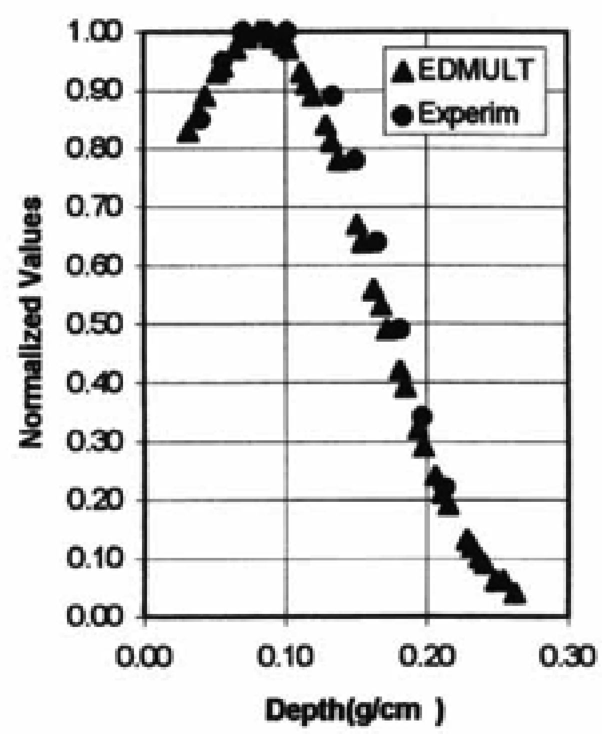

Figure 5. Comparison of Experimental and EDMULT Calculations for Energy Dissipation in CTA for 0.6 MeV Electrons and 9.1 cm Air Gap.

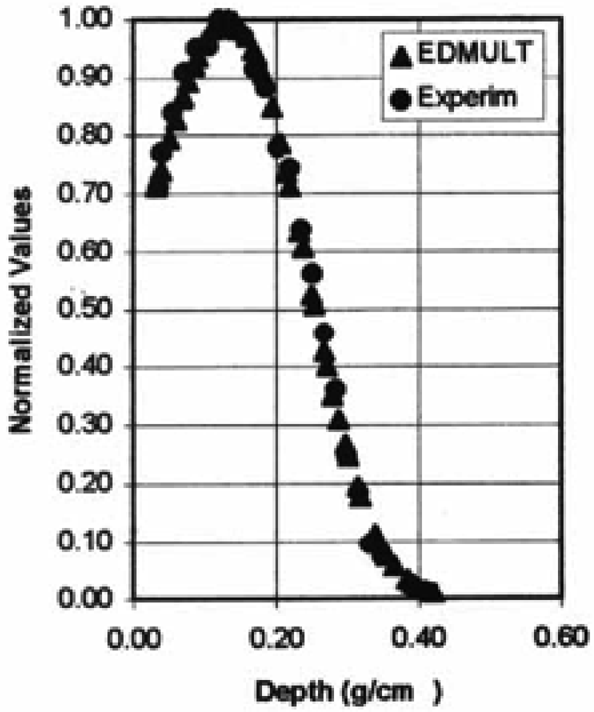

Figure 6. Comparison of experimental and EDMULT calculations for energy dissipation in CTA for 0.8 MeV electrons and 9.1 cm air gap.

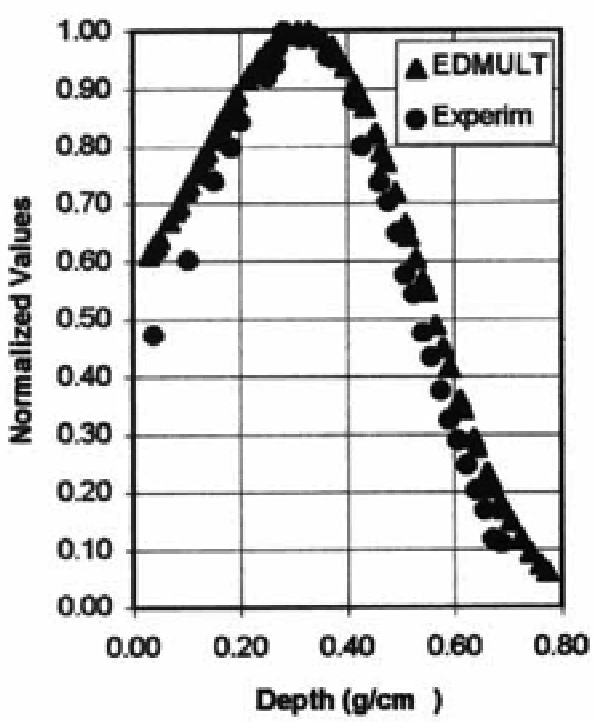

Figure 7. Comparison of Experimental and EDMULT Calculations for Energy Dissipation in CTA for 1.5 MeV Electrons and 9.1 cm Air Gap.

The values between EDMULT calculated and experimental, for the two air gaps, do not match perfectly for all the incident electrons energies because the Edmult code assumes that the beam is completely plane-parallel. This is not true, because for higher energies a scattering in the substrate, where the CTA film stacks are fixed, must be assumed due to a broad-angle incidence of electrons on its surface. For higher air gaps the problem is more accentuated. Another fact is that the EDMULT code was based on experimental data for high energies and when low energies, such as those used in this work, are introduced into the code slightly different values are expected. This fact has been previously observed by Matsuda and Kijima[8] .

Energy Value Determination. R_{50} and R_{ex} values, obtained in the experimental curves, were introduced in Seltzer proposed equations, and electrons energy values were calculated. TABLE 4 show the results.

TABLE 4. Electrons Energies Calulated with Seltzer Empirical Equations by Using the R_{50} and R_{ex} Values.

Nominal Energy (MeV)	CTA - Ti distance (cm)	R_{50} ($g \cdot cm^{-2}$)	R_{ex} ($g \cdot cm^{-2}$)	Calculated Energy (MeV) R_{50}	Calculated Energy (MeV) R_{ex}
0.6	9.1	0.141	0.231	0.516	0.600
0.8		0.222	0.347	0.725	0.808
1.5		0.534	0.713	1.474	1.526
0.6	21	0.122	0.235	0.464	0.540
0.8		0.209	0.334	0.693	0.748
1.5		0.517	0.723	1.428	1.516

It can be observed that the values of R_{50} and R_{ex} for different air gaps are very close. The calculated energy values present some discrepancy probably due to the fact that Seltzer proposed the equations based on specific values connected to the RDI information as irradiation geometry , Ti window thickness, air gap, type of the electron beam (point-monodirectional, plane-perpendicular). The electron beam type is a limiting factor because in the point-monodirectional beam the field size is reduced to a point and in plane-parallel the field size is large and depends on the scanning width and the maximum incident angle to the normal of the substrate, where the material to be irradiated is fixed.

Other explanation about the discrepancies of the calculated values of energy by Seltzer equations is that when R_{50} and R_{ex} are taken from the plotted curves an error can be introduced in depth determination due to graph readings from one to another test. In this work R_{ex} was taken as the value where a tangent, made at the right side of the gaussian cuve (higher depth values), intercepts the depth or x axis. This procedure can introduce errors that will be reflected in the results. So it is concluded that Seltzer equation must be corrected for actual accelerator parameters and irradiation geometries.

From the literature it is known that at the end of the electron energy dissipation curves, the "tail"of the curve, one can take different depth values, i.e., R_{ex} as taken in this work, R_p that is the most probable value and the R_{max} depth value at the point where the energy dissipation curve crosses the x axis.

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