1(8): 01-05
ISSN:2582-9181

Characterization of an X-ray beam by mean energy or effective energy: Comparative Study

Betka Abderrahim[1], Mekarni Fatima[2]
Physics department, science faculty, setif1 university

RESEARCH ARTICLE

Received: **15-08-2021**
Accepted: **25-08-2021**
Published: 28-**08-2021**

Abstract: Radiology is a very important medical imaging technique in the field of medical diagnostics. it uses the X-ray beam. Our objective in this work is to carry out a dosimetric study that confirms or denies the possibility of substitution of the total spectrum of X-rays by the effective energy or the average energy. Using PENELOPE code and the results obtained by this study, we note that the shape of the PDD curve changes with the variation of the beam. In addition, in dosimetry the characterization of an X-ray spectrum by the average energy or the effective energy is not sufficient. On the other hand, the characterization of an X-ray spectrum by effective energy is more efficient than that by average energy.

Keywords: RX, Radiology, Medical imaging, X-ray dosimetry, effective energy, Average energy.

INTRODUCTION:

The aim of this work is to carry out a dosimetric study which can confirm or deny the possibility of substitution of the total X-ray spectrum by the effective energy or the average energy. The deductions to which we will arrive constitute the topic center of this study.

In this study we used the Monte Carlo code PENELOPE to simulate an X-ray generator as well as the interaction of X-ray with a water phantom.

First, we applied the MATERIAL.exe program to generate material data for the geometry of the X-ray tube and the water phantom, both of which are the subject of our study.

Then we applied the PENMAIN program which allowed us to establish the total spectrum of X-rays. Likewise, the PENSLAB program was applied for the determination of the effective energy. The percent depth dose (PDD) as a function of the depth Z of the water phantom, for its part, was obtained from the application of the PENMAIN program starting from the total spectrum of X-rays, the effective energy and the average energy of the total X-ray spectrum.

All the results obtained were processed by the Origin 8.0 software from which we established the PDD curves, the latter having been subjected to a comparative study.

Method and Results

The choice of the Monte Carlo PENELOPE code is justified by its advantages, in this case the precision of the simulation and the flexibility of the code. Indeed, its sophisticated electronic distribution model, its speed of execution and its precision make it a privileged alternative suitable for carrying out such tasks wisely.

The PENMAIN and PENSLAB user programs inherent in the PENELOPE code applied to perform a simulation require the data files, namely, the geometry file, the material file and the input file.

The Material.exe program is used to generate the digital database containing the physical parameters used by Penelope for the simulation, namely cross sections, coefficients of attenuation, stopping powers, density and others.

The different materials composing the X-ray tube, the water phantom and their dimensions were used to carry out the simulation as indicated in the following table:

Material number	Material type	Function
Material 1	Tungsten	Anode Constitutes
Material 2	Aluminum	RX filter
Material 3	Water	Water phantom

Table 1: Types of X-ray tube and water phantom materials and their functions.

The PENGEOM program is used to model the water phantom and the X-ray tube. All the information relating to the dimensions of the water phantom, the anode, the filter and the detector can be accessed via the geometry file.

After modeling the simulated device, the studied geometry is verified by means of the GVIEW2D program.

1(8): 01-05
ISSN:2582-9181

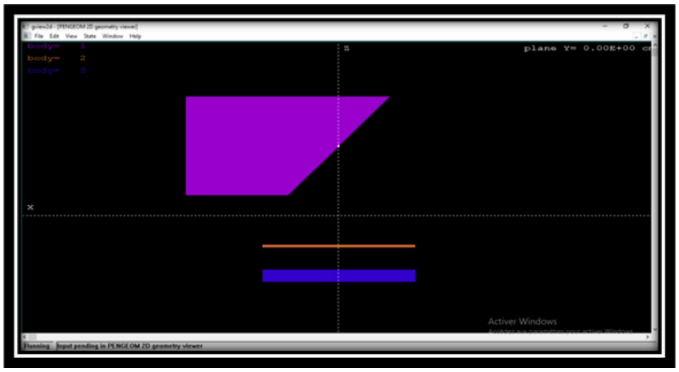

Figure 1. Tube geometry along the displayed Y axis

The simulation, using the input files, is carried out according to the following procedure:

a. Determination of RX spectrum:

To determine the spectrum at X-ray, we have prepared the geometric file of the tube at X-ray and the input file.

The use of data from the output files allowed us to obtain the spectrum presented in figure 2

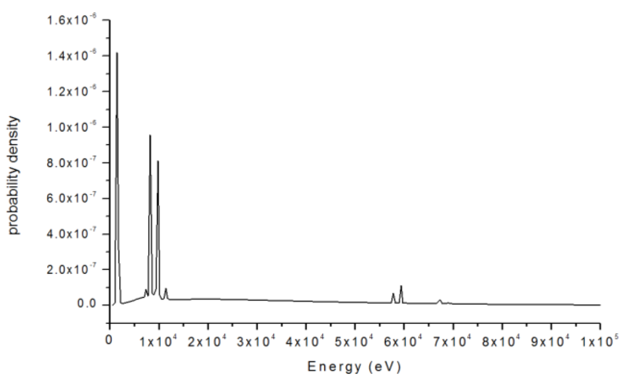

Figure 2. X-ray spectrum obtained by simulation.

b. Determination of effective energy

To determine the effective energy, we first proceeded to the determination of the half-value layer (HVL), by studying the transmission of photons of the simulated X-ray spectrum as a function of different water thicknesses.

We have repeated this step in nine times. In each time, we modify the thickness in order to evaluate the transmission coefficient as shown in the following table:

Thickness X (cm)	Ratio of transmitted intensity / primary intensity (I_t/I_0)
0.05	0.6655251
0.1	0.5932105
0.15	0.5427180
0.20	0.5061481
0.21	0.4992464
0.25	0.4773620
8	0.1030051
8.2	0.09999079
8.3	0.09825220

Table 2. Variation of the transmission ratio (It / I0) as a function of the thickness (x) for the total spectrum of X-rays.

From table 2, we have drawn the curve below**:**

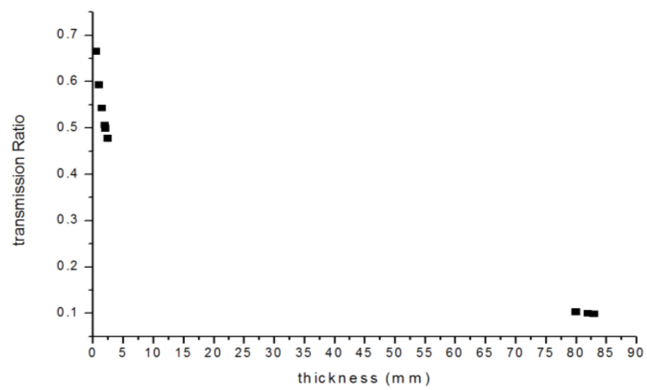

Figure 3. Variation of transmission ratio as a function of thickness (x)

From figure 3 which represents the variation of the transmission ratio according to the thickness (x) of the total spectrum of the X-rays, it turns out that the ratio of the intensities decreases with the increase in the thickness of the water layers . However, the amount of X-ray absorbed is greater as the thickness of the layers increases. Thus, the intensity ratio fell from 0.66 to 0.098 for a 9 thickness increasing, in this case from 0.5mm to 83 mm; a logical evolution, given, on the one hand, the thicknesses of the water layers growing in increasing order.

From the curve of the variation of the ratio of the intensity (It / I₀) as a function of the thickness (x) of the total spectrum of X-rays, we found that the HVL is equal to 2.1mm of water.

1(8): 01-05
ISSN:2582-9181

The attenuation as a function of the thickness of the target is given by the Lambert equation (1):

$$I(X) = I0 \times e^{-\mu x} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Such as :

I_0 : primary beam intensity

I : intensity of the beam passing through a thick absorber 'x'

μ : attenuation coefficient

x : material thicknessComme :

$$I\,(CDA) = \frac{I_0}{2} = I_o * e^{-\mu\,.\,CDA}$$

So, we get that: $\mu = \frac{\ln 2}{CDA}$

⇨ $\mu = \frac{\ln 2}{2.1} = 0.33\ mm^{-1}$

From the table showing the attenuation coefficient as a function of energy. We performed a linear interpolation to have the energy corresponding to the average attenuation coefficient of our obtained spectrum (μ = 0.33 mm-1). This energy is called effective energy.

Finally the effective energy obtained for our spectrum is:

Eeff = 11854 eV

a. Determination of PDD as a function of Z, using the total spectrum of X-rays:

For the determination of the PDD as a function of Z using the total spectrum of the X-rays, we developed the geometric file of the water phantom and the input file.

The output file expressing the dose as a function of Z makes it possible to plot the behavior of PDD (Percent depth dose) presented in Figure 4

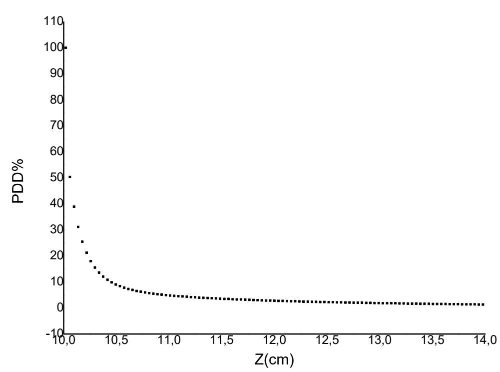

Figure 4: PDD with the total spectrum of RX.

From figure 4 expressing the variation of the PDD (percent depth dose) as a function of the depth (Z) in the water using the total spectrum of the X-rays, it turns out that the variation of PDD decreases with increasing depth (Z) of the water phantom, the depth of maximum dose (Zmax) is equal to 0.1mm and the depth of PDD equal 50% (R_{50}) is equal to 0.5 mm.

b. Determination of PDD using effective energy:

For the determination of the PDD as a function of Z using the effective energy, we replaced the total spectrum of the X-rays by the effective energy (11854 eV), then we started the simulation using the PANMAIN program. The PDD obtained is shown in figure 5.

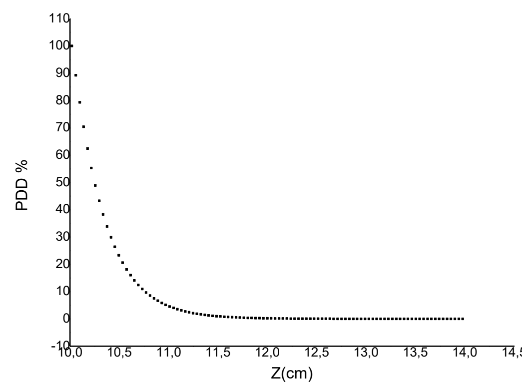

Figure 5: PDD with effective energy.

Figure 5 illustrating the variation of the PDD as a function of the depth (Z) with the effective energy, shows a behavior quite similar to that observed in the previous experiment Fig 4. In addition, the depth of maximum dose (Zmax) in the water phantom will be surrounding of 0.1 mm. The depth of PDD equal to 50% (R50) is equal environ 0.25 mm.

c. Determination of PDD as a function of Z using average (mean) energy:

To determine the PDD as a function of Z using the average energy, we first calculated its value, which is 22.06 keV.

The PDD obtained in this case is shown in figure 6.

1(8): 01-05
ISSN:2582-9181

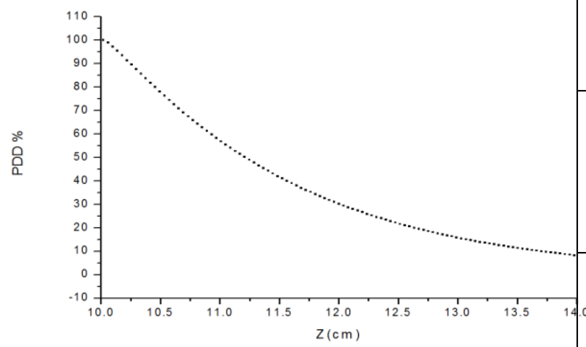

Figure 6: PDD with average energy

From figure 6, representing the variation of the PDD as a function of the depth (Z) in the water phantom using the average energy, shows an observation according to which the PDD is equal to 50% at the depth (R50) is equal environ 0.1 mm and the depth of maximum dose (Zmax) is approximately 1.4 mm.

f. Comparison of the three experiences:

In order to make a comparison, we have drawn up the graph (figure 7) representing the variation of PDD as a function of the depth obtained by the three previous simulations.

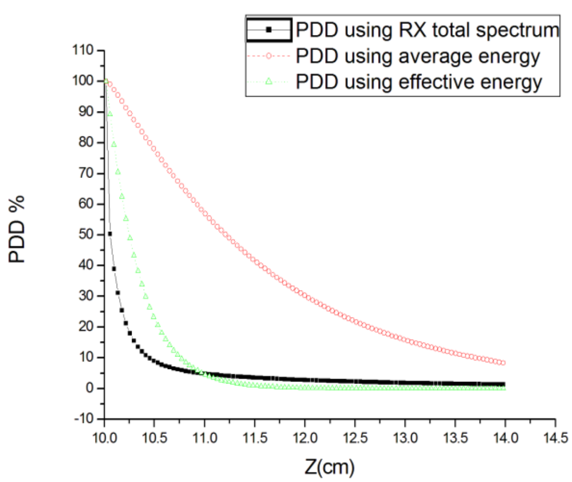

Figure 7: PDD variation with respect to depth (z) with the total X-ray spectrum, effective energy and average energy.

For the interpretation of Figure 7, we calculated the difference between the values of Z max and R_{50} of the effective energy, the average energy and that of the total spectrum.

	Z_{max} (mm)	R_{50}(mm)	ΔZ_{max} (mm)	ΔR_{50} (mm)
The total spectrum of X-rays	0.1	0.5	0	0
Effective energy	0.1	3.3	0	2.8
Average energy	0.1	12	0	11.5

Table 3: Comparison between Z max and R_{50}

In addition, the average difference between doses at different depths using effective energy and those using the spectrum is around 35%.

From the three experiments described in FIG. 7, it is noted that the shape of the curve changes with the beam used. The change in the shape of the curve is explained by the influence of energy on the dose. Then, the comparison of PDD, Zmax and R_{50} of the different beams (Table 3 and Figure 7) shows that in a dosimetric study the characterization of an X-ray spectrum by the effective energy is more efficient than that by the average energy. But remains insufficient especially for radiotherapy at which the doses are high.

Conclusion:

From the results obtained by this study, we note that the behavior of the PDD curve changes with the variation of the beam. In addition, in dosimetry the characterization of an X-ray spectrum by the average energy or the effective energy is not sufficient. On the other hand, the characterization of an X-ray spectrum by effective energy is more efficient than that by average energy.

REFERENCES.

[1] Toshiyuki NAKAJIMA and Mitsue CHIBA, Journal of NUCLEAR SCIENCE and TECHNOLOGY, 23[3], pp. 258-266 (March 1986)

[2] L. A. R. DA ROSA* and H. P. NETTE, Appl. Radiar. Isot. Vol. 39, No. 3. pp. 191-197, (1988)

[3] J R Greening, Medical Physics Handbooks 15 Fundamentals of Radiation Dosimetry, Taylor & Francis Group, New York London (1985)

[4] M. G. Petrushansky,Biomedical Engineering, Vol. 48, No. 5, January, 2015, pp. 249-252

[5] Ahmed Azbouche, mémoire de magister " ETUDE PAR LE CODE MONTE CARLO PENELOPE DES FAISCEAUX

1(8): 01-05
ISSN:2582-9181

DE RAYONS X PRODUITS PAR DES GENERATEURS DE RAYONS X DE BASSE ENERGIE UTILISES EN RADIOTHERAPIE". octobre 2009.

[6] ERVIN. B.PODGORSAK "Radiation Physics for Medical Physicists". Edition: Springer, 2éme édition (2010), ISBN 978-3-642-00874-0.

[7] J.H. HUBBELL; Photons Mass Attenuation and Energy-absorption Coefficients from 1 keV to 20 MeV. Int. J. Appl. Radiat. Isot., Vol.33, 1269-1290. (1982)

[8] INTERNATIONAL ATOMIC ENERGY AGENCY "Radiation oncology physics: handbook for teachers and students", ISBN 92–0–107304–6,(Vienna, 2005).

[9] PENELOPE-2003 : PENELOPE – A Code System for Monte Carlo Simulation of Electron and Photon Transport Workshop Proceedings Issy-les-Moulineaux, France 7-10 July 2003.

[10] PENELOPE 2006 : A Code System for Monte Carlo Simulation of Electron and Photon Transport Workshop Proceedings Barcelona, Spain 4-7 July 2006

[PEN 08] PENELOPE-2008: A Code System for Monte Carlo Simulation of Electron and Photon Transport Workshop Proceedings Barcelona, Spain 4-7 July 2008.