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Evaluation of photon and neutron dose distribution from the Varian Clinac 2300EX 15 MV medical LINAC with MCNP6 Code

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Evaluation of photon and neutron dose distribution from the Varian Clinac 2300EX 15 MV medical LINAC with MCNP6 Code

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Abstract. The X-ray and neutron beam characteristics of the Varian Clinac 2300EX LINAC were obtained by simulation and computation using the MCNP6 software. An electron source with an energy of 15 MeV is used to produce an X-ray beam which is then directed to the phantom 100 cm distance from the electron source. With an irradiated area (10x10) cm^2, the average X-ray dose on the phantom surface obtained was (2,91 ± 0,47) 10^{-15} Gy/e. For better isodosis, a triangular prism-shaped within nickel material flattening filter was installed to produce an X-ray beam profile with an average dose of (2,04 ± 0,22) 10^{-16} Gy/e. During LINAC 15 MV operation, the mean neutron dose was detected (8,57 ± 0,55) 10^{-20} Sv/e. The neutron energy spectrum has been simulated, the distribution of thermal energy intensity is 0,06%, epithermal energy is 0,74%, and the most distribution is fast energy 99,20%. The ratio of neutron equivalent dose to the central axis X-ray dose (ξ) was calculated. The value of ξ meets the allowable limit of <1/1000 Sv/Gy, recommended by the International Electrotechnical Commission (IEC). The ξ values obtained at several phantom depths in this study indicate the values allowed by the IEC.

1. Introduction

At this time LINAC became a radiotherapy method that has dominated about 60% of the use of radiotherapy treatment because it is more beneficial for safety and dosimetry reasons (Page., 2014). LINAC radiation energy can reach the order of tens of MeV, when compared with cobalt-60 radioactive aircraft around 1.17 MeV and 1.33 MeV energy [1].

LINAC operation by setting above 8 MV high voltage which produces 8 MeV electron energy and then produces X-ray radiation accompanied by neutron radiation in X-ray mode. Bremstrahlung X-rays produced have a spectrum of energy distribution from 0 to 8 MeV and the characteristics of the beam need to be described.Very high X-ray energy has the potential to interact with the material in LINAC to form a photoneutron reaction (γ, n) to produce a neutron beam .

These neutrons are mainly produced by X-ray collisions with components present on the LINAC head from metal elements including targets, filters, collimators and other materials. Neutrons are produced when the energy conditions of X-rays (Eγ) are greater than the energy of the reaction threshold (γ, n), which will depend on the type of elements subject to X-rays [2].

Dosimetry information from neutrons is needed because neutrons have a very high radiation weight factor (Wr) depending on their energy, so its can provide additional doses apart from their own X-rays [3]. Direct measurement of the radiation field requires a measuring instrument that is not necessarily owned by the LINAC owner. Therefore simulation and computation are very helpful for estimating the condition of neutron generated by LINAC. MCNP6 is a type of modeling software that uses Monte Carlo simulation methods by tracking across many types of particles behavior such as electron particles, protons, neutrons, alpha, beta, and gamma[4].

Research with MCNP was carried out with Variant Clinac type 2100C/D to predict the output of photon and neutron spectra under the flattening filter at the center of the axis (isocenter). It was found that the Bremsstrahlung spectra had a maximum value between 1 and 2 MeV energy and the neutron spectra had 2 peaks which were around 0.3 - 0.5 MeV and 1.2 - 2 MeV [5].

Permatasari (2018) has succeeded in making a simulation for LINAC Variant Clinac 2300EX obtained that the distribution of X-rays produced by Variant Clinac 2300EX is dominated by the highest intensity in the range of 1 MeV to 2 MeV and X-ray energy which has energy of the source electron with the least value of intensity[4].

Taleb et al., (2018) who conducted a study with MCNP5 to evaluate photoneutrons from LINAC type Electa Precise 15 MV found that the maximum photoneutron flux was 3,346 x 10^{-9} n/cm^2-e with a surface area of 30 x 30 cm^2 and it was shown that the dose the neutron equivalent decreases in value as it goes into the phantom depth of water. With the aim of providing new information and difficulties in making direct measurements in the human body, a simulation study of photon and neutron doses of the LINAC type Variant Clinac 2300EX 15 MV was used in the phantom of water[6].

Information about X-ray and neutron doses at each phantom depth is also very necessary for radiation therapy. The International Electrotechnical Commission (IEC) gives a reference to the permit that the ratio of neutron doses to the photon position at the center of the axis is below 1 x 10^{-3} Sv/Gy [7].

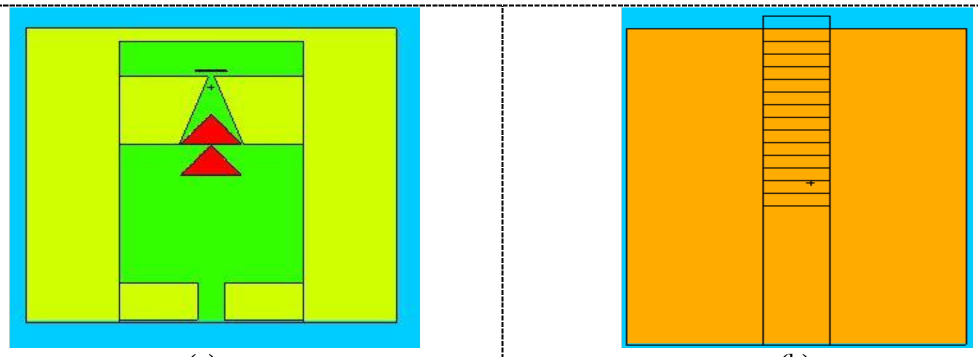
2. Experimentals

2.1 Method

Geometry and materials refer to Van Dyk's research, compiled with Vised and MCNP6 to produce a design [8] on Figure 1 with material characteristics are written in table 1.

Table 1. Charateristics of material used to model the Varian Clinac LINAC.

Geomethry	**Material**	**Density (gr.cm^{-3})**
Cover	Lead (Pb)	11.35
Target	Tungsten (W)	19.3
Collimator	Lead (Pb)	11.35
Water Phantom	Water	0.9982
LINAC Environment	Air	0.001205
Filter	Nickel	8,03



(a) (b)

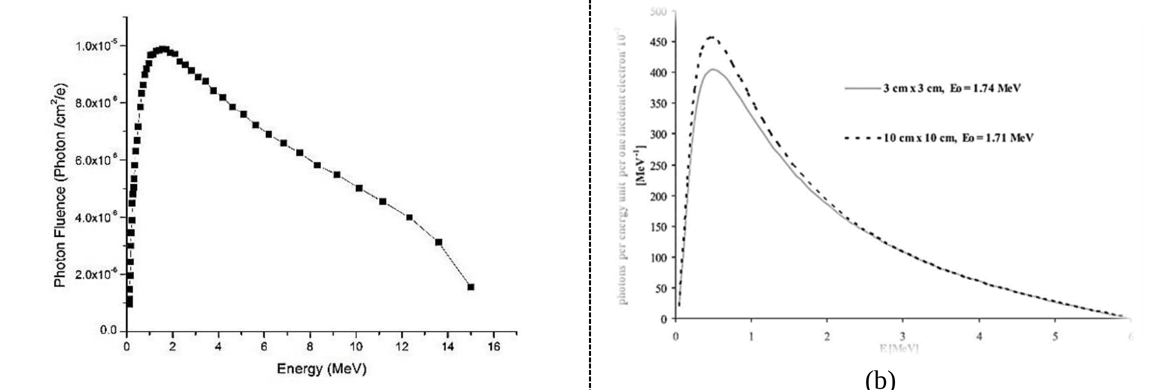
Figure 1. Schematic of the simulated of the Varian Clinac 2300EX (a) The LINAC Head (b) Water Phantom.

The 15 MeV electron source is assumed to be homogeneously monodirectional out of the disk (disk) 3 mm in diameter and 5 mm thick, fired at the Tungsten target a distance of 3 cm in front of it. Tally F4 on MCNP6 is used as a detector that gives an output in the form of the value of the average flux value through the soft tissue in units of Neutron/cm^2.e in the exposure time of 1 second. This tally is right in an area of 10 x 10 cm^2 in water phantom with a volume of 50 x 50 x 50 cm^3, and is located on a 100 cm SSD. Tally Dose Energy (DE) is also used in MeV and Tally DF (E) for converted the flux unit value to be equivalent dose unit values, with reference to ICRP-21 (1971). The figures obtained will be presented in graphical form.

3. Result and Discussions

3.1 X-ray Characteristics

To ascertain the characteristics of the X-rays produced, the data are presented in Figure 2.a

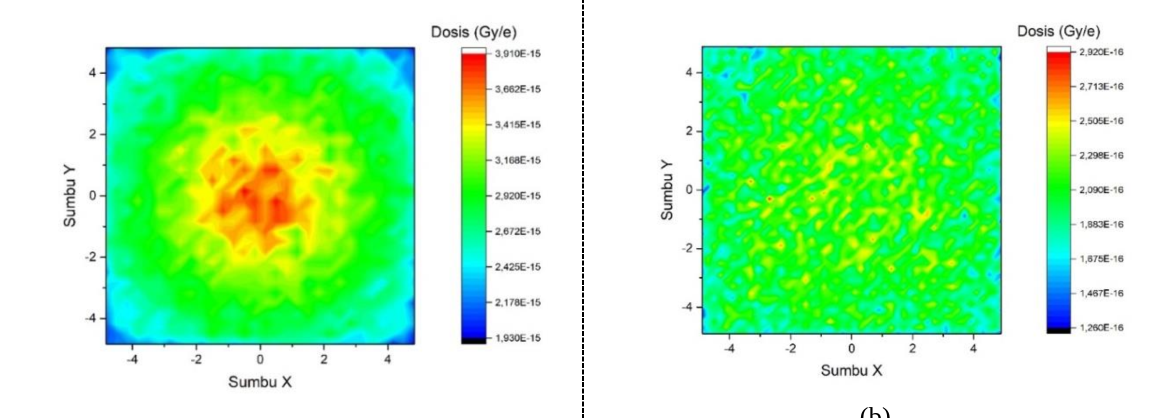


(a) (b)

Figure 2. X-ray spectra Varian Clinac 2300EX LINAC (a) 15 MV this work and (b) by Adam 2015.

The graphic form of the X-ray energy distribution has been confirmed with the results of the 2019 limitation of the LINAC Variant Clinac 2300EX X-ray spectrum. Shown in the graphic figure 2.a compared to the graphic figure 2.b has the same meaning of distribution for X-ray energy to its intensity flux. The X-rays produced by LINAC 15 MV have a maximum energy of 15 MeV but the amount is very small. From this graph the spectra energy dominated by X-Ray with energy around 1 MeV to 2 MeV and within the highest intensity energy is 1.52 MeV.

If the X-ray beam is drawn on a 10 x 10 cm^2 field area, the dose rate characteristics obtained in Figure 3.a are obtained.



(a) (b)

Figure 3. X-ray dose distribution at the surface water phantom for field size 10 x 10 cm^2 water phantom (a) without filter (b) within filter.

In the middle area of the field, the highest dose was obtained was (3.91 ± 0.14) 10^{-15} Gy/e. The average value of the dose of X-rays on the phantom surface was (2.91 ± 0.47) 10^{-15} Gy/e with a non-homogeneous percentage in terms of standard deviation has an average value of 22.85%. To more get the isodose value, a filter is installed. Filters made from nickel with a triangular prism form are installed so that the X-ray dose distribution characteristics of the filter installation are shown in Figure 3.b. With a filter installed, the average dose of X-rays on the phantom surface was (2.04 ± 0.22) 10^{-16} Gy/e with the percentage dropping to 10.66%. This shows that the distribution of doses in each part of the irradiation surface is uniform or homogeneous. This can also be seen in the contour graph of the figure 3.b that high doses have not been collected in the middle of the broad field.

3.2 Neutron Characteristics

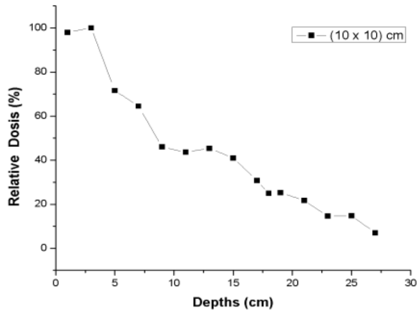


Figure 4. Dose distribute on depth function Varian Clinac 2300EX medical LINAC

Graphs of absorbance dose at phantom depth with irradiated surface area of 10 x 10 cm^2 has the maximum neutron absorption dose value is (2.92 ± 0.27) 10-17 mSv/e at depth of 2 - 4 cm. The shape of the graph has pattern that is getting deeper into the depth of the neutron equivalent dose the lower the value. So at a depth of 2 - 4 cm, the greatest absorption of neutron radiation occurs, then it will decrease exponentially at the next depth.

The limitation that neutrons are divided into 3 types according to their energy, namely thermal neutrons (En = 0.025 eV), epithermal neutrons (1 eV <En <10 keV), and fast neutrons (10 keV <En <1 MeV). The simulation results obtained for NPS 200 million and was made on graph like as figure 5.a, about percentage of energy flux from the total flux intensity for thermal energy flux of 0.06%, for epithermal energy flux of 0.74%, and for fast energy flux of 99.20%. Showing that fast neutrons have the greatest intensity and dominate neutrons resulting from X-ray beam irradiation in LINAC Varian Clinac 15 MV. It is connected with the radiation weight factor (Wr) with the provisions of ICRP No. 103 of 2007 if the danger level of the neutrons produced has a dominance of 20 times more dangerous than its own X-rays.

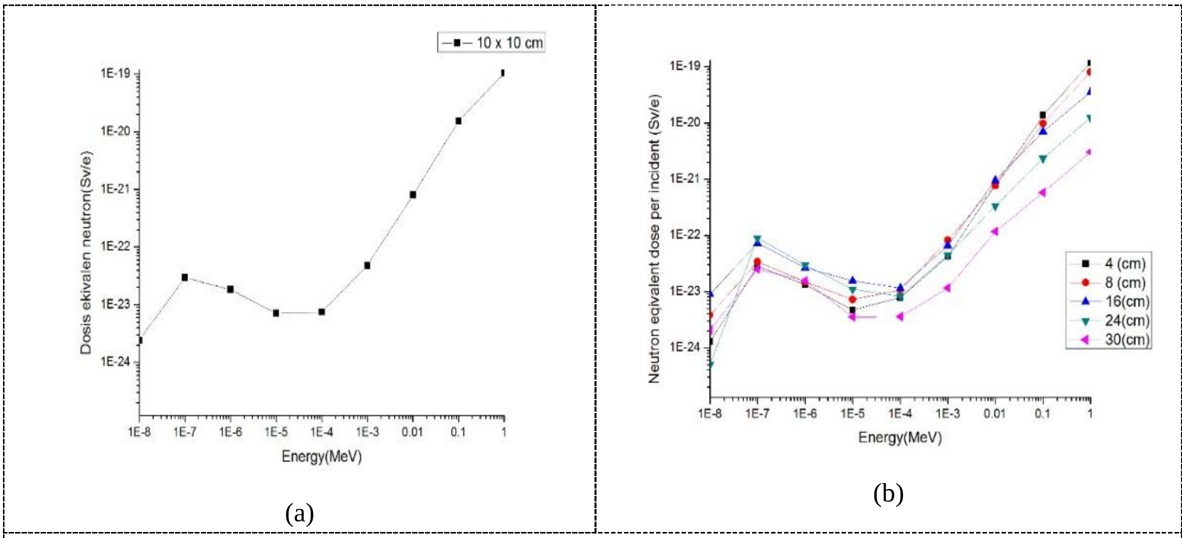


Figure 5. Neutron spectra at different depth in water phantom for field size 10 x 10 cm^2 (a) Depth of 4 cm until 6 cm (b) Various depth

Also simulated the depth of the water phantom to determine the effect of depth on the energy distribution of the neutrons shown in graphs in Figure 5.b It can be seen that the number of neutrons rapidly decreases with depth. This is due to the process of neutron energy thermalization by water which experiences the event of energy absorption by the environment of the neutron particles. The total value of neutron flux decreases as it goes into phantom depth due to the decreasing amount of neutron thermal energy.

The output data for neutron dose and X-ray dose with an area of 10 x 10 cm^2 at each depth were collected and a ratio of the two quantities was made as in table 2. Table 2 shows that the neutron dose ratio and the X-ray dose in this study have met the specification standard permit from the IEC, namely the permit limit <1 mSv / Gy Therefore, the neutron beam results from the LINAC mode X-ray variant Clinac 2300EX 15 MV can be declared safe for patient for cancer radiotherapy.

Table 2 Neutron Equivalent Dose to X-Ray Dose Ratio Data

Depths (cm)	Equivalent Dose Neutron (mSv/e)	Dose Sinar-X (Gy)	Ratio (mSv/Gy)
2	2,87E-17	1,99E-16	0,14
4	2,93E-17	1,87E-16	0,16
6	2,10E-17	1,74E-16	0,12
8	1,89E-17	1,61E-16	0,12
10	1,35E-17	1,49E-16	0,09
12	1,28E-17	1,38E-16	0,09
14	1,33E-17	1,28E-16	0,10
16	1,20E-17	1,09E-16	0,11
18	9,00E-18	1,01E-16	0,09
20	7,30E-18	9,37E-17	0,08
22	7,38E-18	8,67E-17	0,09
24	6,35E-18	8,02E-17	0,08
26	4,28E-18	7,44E-17	0,06
28	4,33E-18	4,86E-17	0,09

4. Conclusion

Simulation of photon and neutron doses produced by Variant Clinac 2300EX 15 MV medical LINAC using MCNP6 has been carried out to characterize the X-ray spectrum, X-ray isodose, neutron spectrum and neutron dose. The ratio of the neutron equivalent dose to the photon dose at the center of the axis is lower at the licensing limit by the IEC of 1 mSv/ Gy within the mean value obtained was 0,11 mSV/Gy so that it is fulfilled by Varian Clinac 2300EX 15 MV medical LINAC.

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