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Distributions Dose Analysis for 6 MV Photon Beams Using Monte Carlo-GEANT4 Simulation

Nurul Qomariyah[1,b)], Rahadi Wirawan[1, a)], Laili Mardiana[1] and Kasnawi Al Hadi[1]

[1]Department of Physics, Faculty of Mathematics and Natural Sciences, UniversitasMataram, Jl. Majapahit No. 62
83125 Mataram, Indonesia

a)Corresponding author: rwirawan@unram.ac.id
b)nurulqomariyah@unram.ac.id

Abstract. Monte Carlo is a method that widely used for calculation of particle transport in radiotherapy dose distribution. This study was devoted to develop a linear accelerator head geometry model (LINAC) using GEANT4 simulation for 6 MeV photon beam. The geometric model of the accelerator head consists of electron sources, target, primary collimator, flattening filter, jaws, and MLC (multi-leaf collimator). The homogeneous water phantom size of 40 x 40 x 40 cm^3 was used in the simulation, 100 cm SSD (source-skin distance), and field size are 5 cm x 5 cm, 10 cm x 10 cm, 20 cm x 20 cm, and 30 cm x 30 cm. The simulation results show the peak curve energy positions are in the range 0.3 MeV – 0.4 MeV and the maximum absorbed energy is about 5.9 MeV. According to the landau curve fitting the mean energy is about 0.385 MeV. The results of GEANT4 simulation show the energy spectrum has the same pattern as an energy spectrum from several experiments of LINAC head geometry. The simulation results also show the dose distribution based on beam profile and depth profile of water phantom with different fields.

INTRODUCTION

Radiotherapy is a treatment to eliminate cancer cells with high-energy electromagnetic radiation. LINAC is a radiotherapy device that can produce electrons for ionization applied for cancer therapy near the surface, and produce high-energy photons or X-rays if they interact with targets for deep cancer therapy [1]. One of the success factors of radiotherapy is giving the accurate dose to the target organ from calculating of the dose distribution during the simulation of the Treatment Planning System (TPS). Pre-treatment simulations were carried out for quality control and dose limit values to be given to patients [2]. Simulation provides an important role in estimating the actual dose distribution of radiation before radiotherapy because direct measurement in patients is difficult to do with many stages of the process [2-4].

GEANT4 simulation is widely used in the movement of particles using the Monte Carlo code because of its ease and uniqueness. GEANT4 can model sources and geometries in motion on the head of LINAC such as rotating parts of the IMRT ray line (modulation intensity therapy), dynamic MLC (Multi-leaf Collimators), and moving parts of the LINAC system so that it can help in radiotherapy simulation using LINAC [5]. The Monte Carlo method has been commonly used to observe particle interactions in radiotherapy treatment and has been optimized for its use. The Monte Carlo method is used to model radiation interactions that can describe real conditions so that it can be used in dose optimizing [3, 4, 6]. Monte Carlo/GEANT4 is used to simulate the geometry of the LINAC head to determine the distribution of radiation energy generated after interacting with materials in the LINAC parts [7, 8]. The Monte Carlo method is imperative for verification on radiotherapy [9].

To get an accurate dose calculation, it is necessary to analyze the energy spectrum from LINAC. So it is essential to study the reconstruction of the LINAC head to determine the quality of the photon beam produced [10]. This study was conducted to develop a geometric model of the head of LINAC using Monte Carlo/GEANT4 simulation with energy 6 MV photon beam to observe the dose distribution in the homogeneous water phantom.

METHOD

In this research, the geometric design of the linear accelerator head was simulated to produce the high energy electron beam 6 MeV. The geometry of LINAC head built consists of several main parts which are electron source, target and primary collimator, flattening filter, X-jaws, Z-Jaws and multi leaf collimator (MLC) as shown in Figure 1. The geometric design of a LINAC head was built using the GEANT4 simulation toolkit. The electron beam is shaped like a pencil beam and emits a monoenergetic beams 6 MV that directly interacts with a tungsten target. The tungsten target has 0.15 cm thickness and a radius 0.5 cm. Bremsstrahlung X-rays are produced from electron beam interactions with the target resulting in a continuous energy distribution of 0 to 6 MeV. The primary collimator is made of tungsten which has the shape of a cylinder with a cone-shaped hole inside. This primary collimator plays a role in limiting the movement of photon beam to get out through the flattening filter. A flattening filter (FF) was attached to the bottom of the primary collimator in order to make a homogeneous/uniform photon beam. The FF form is cone-flat made from tungsten material and have a dimension 1.94 cm of height and a radius of 3.81 cm [11]. A pair of jaws is used to shape the field of the beam in the phantom surface. The jaws are made from tungsten and have dimension 20 cm x 20 cm x 7.8 cm thickness. MLC (20 cm x 5.5 cm x 2.0 cm) is used to form and pass a uniform photon beam with a square field area of a water phantom frame according to the size of 40 x 40 x 40 cm^3.
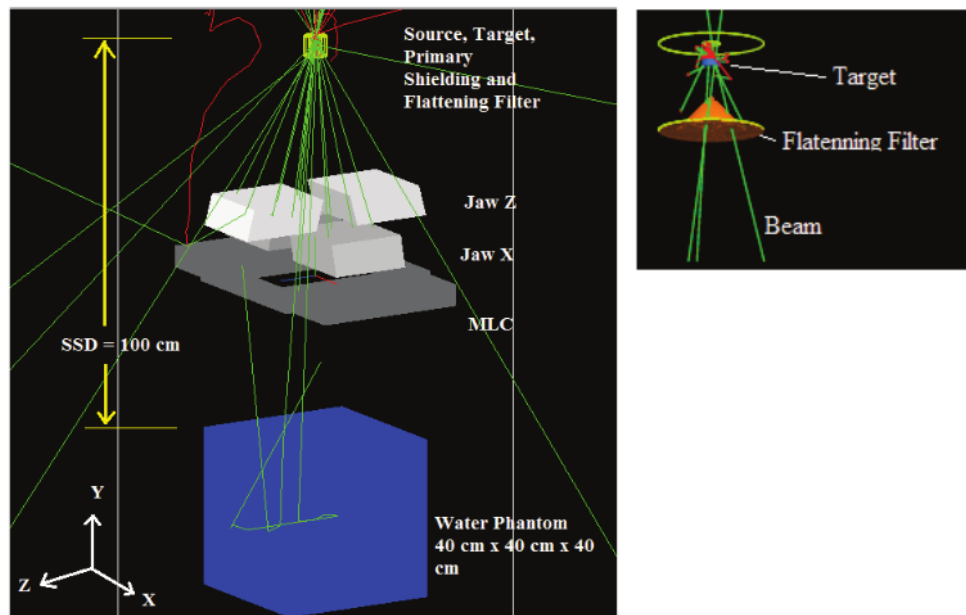

FIGURE 1. Design of the LINAC geometry model

The simulation is carried out in several steps, the first step simulating the radiation interaction with the accelerator head parts to produce a spectrum of energy distribution of the electron beam. The electron energy spectrum is determined based on the difference in irradiation area on the surface of a homogeneous water phantom with a single energy of 6 MeV. The next step is analyzing the dose distribution in depth profile and the beam profile.

The photon energy spectrum from the accelerator was running using electron beam sampling with 1×10^7 beam on to the water phantom surfaces with varying field sizes 5 cm x 5 cm, 10 cm x10 cm, 20 cm x 20 cm, 30 cm x 30 cm and the source skin distance (SSD) equal to 100 cm referring to clinical requirements, and source to kilometer distance (SCD) equal to 60 cm. In order to determinate the beam profile, the spatial range of measurement for ionization chamber position on the x-axis is about 1.5 cm for field size 10 cm x 10 cm, and 3 cm for field size 20 cm

x 20 cm and 30 cm x 30 cm. Depth of chamber position is 1 cm from the surface of water phantom. Observations on depth doses were carried out by measuring energy deposition at 1 cm, 5 cm, 10 cm, 15 cm, 20 cm and 30 cm of depth. In this simulation, 0.6 cm^3 was set up as a sensitive material volume of an ion chamber to optimize the beam detection.

RESULT AND DISCUSSION

In radiotherapy using LINAC there are several crucial factors used in controlling the quality of measurements seen from the distribution of the doses produced. These factors are percentage depth dose (PDD) and beam profile (BP) curve. Depth profile provides information about the quality of light so that the dose can be maximized on the field and the desired depth. Beam profile provides the same information for lateral distribution of doses. Before looking at the distribution dose, it is necessary to analyze the radiation energy spectrum to validate whether the photon beam is in accordance with the energy spectrum of the experimental results so that it can be used for clinical purposes.

In this simulation, electrons are generated by 1 x 10^7 electrons with a pencil beam source that is set using the primary collimator on the LINAC head. To produce a clinical photon beam, the electron beam passes the tungsten target to produce a bremsstrahlung spectrum-ray on the phantom surface. The spectrum is observed from energy 0.001 MeV to 6 MeV. The radiation beam size is 10 cm x 10 cm, 20 cm x 20 cm, and 30 cm x 30 cm and SSD was set up to 100 cm which can be seen in Fig. 2.
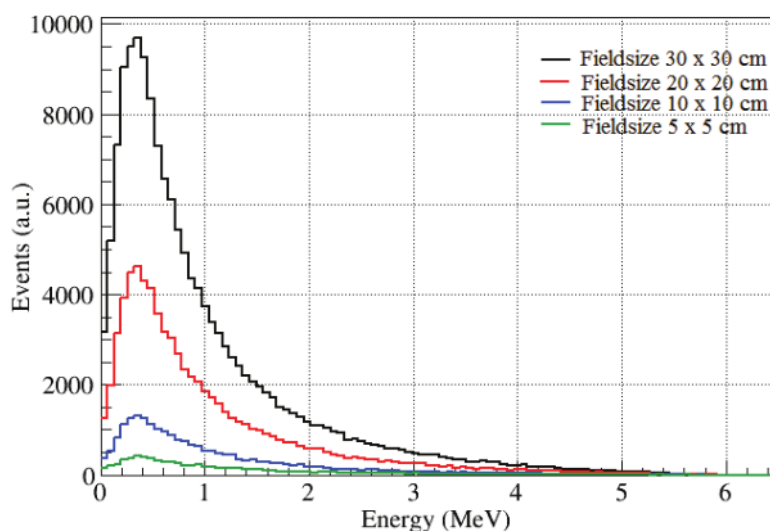

FIGURE 2. Energy spectrum distribution absorbed by water phantom

Analysis of the Energy Spectrum

From Fig. 2 shows the peak curve energy position is 0.3 MeV – 0.4 MeV and the maximum absorbed energy is about 5.9 MeV. According to the landau curve fitting the mean energy is about 0.385 MeV. The field size of radiation beam gives an effect to the total energy that absorbed by the phantom as depicted by the peak height energy curve as showed in the Fig. 2. The curve is based on a Monte Carlo GEANT4 simulation which has been validated in accordance with the experimental results. The result of electron radiation beam simulation using the geometry of LINAC head, which developed in this study shows the characteristics of the photon energy spectrum was appropriate to energy spectrum from the several experimental results.

Photon fluence intensity experiences a rapid increase in energy below peak energy and decreases slowly over peak energy. The larger of the radiation field that setup gives a higher photon fluence and conversely. So, the larger the field size increases the intensity of the photon that reaches the phantom surface.

Analysis of Beam Profile and Depth Deposit Energy

The dose distribution of the beam profile (BP) is analyzed based on the deposit energy information. This simulation result of the beam profile (BP) in the water phantom was presented in figure 3a. A curve of deposit energy beam tends to decrease near the edge of the field size which defined as penumbra region. It can observe at 5 cm lateral position for field size 10 cm x 10 cm, 10 cm for field size 20 cm x 20 cm and 15 cm for field size 30 cm x 30 cm. That condition due to the restrictions setup of exposure field by the jaw collimator. The slope of the curve profile in the penumbra region depends on the field size. The slope of the curve profile is sharper for larger field sizes.

BP is strongly influenced by symmetry and FF features. Changes in the energy spectrum distribution are very sensitive to FF features both from changes in flatness thickness or position. In this study, BP results were strongly influenced by the dimensions of the cone-shaped FF so that it was seen the deposited energy at the axis quite low.

Analysis of Depth Deposit Energy

Figure 3(b) shows the depth profile curve of energy deposition in a water phantom for each field size 10 cm x 10 cm; 20 cm x 20 cm and 30 cm x 30 cm. In clinical application, observation of depth dose profile usually conducted on the depth 20 cm or 30 cm [3]. Based on the information, we conduct the simulation of measurement up to 30 cm in depth. In the figure, the depth profile curve tends to decrease with increasing depth of the ion chamber position. The fluctuation on the energy deposition curve was influenced by the scattering effect of phantom material. In this study, we did not obtain the depth of maximum energy deposited which the result of buildup factors. Therefore, we do not determine the percentage dose depth.
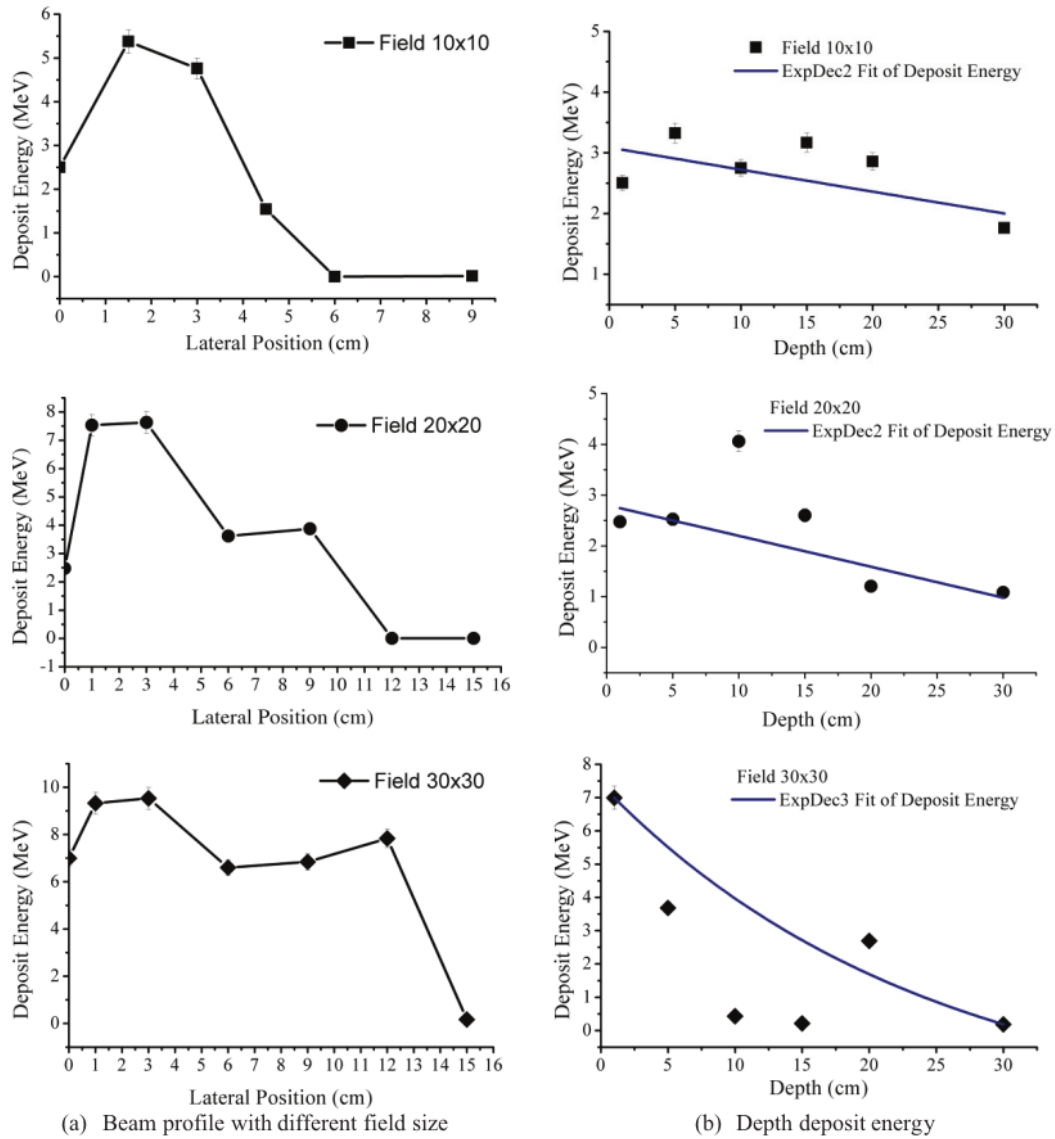
(a) Beam profile with different field size   (b) Depth deposit energy

FIGURE 3. Beam profile of deposit energy and depth deposit energy

CONCLUSION

This paper presents the Monte Carlo GEANT4 simulation to predict the dose distribution of the LINAC head geometry model on homogeneous water phantoms. The results obtained from the simulation can explain the dose distribution can be observed through a beam profile and profile depth. The future work in our study is to observe the scattering effect of shielding radiation feature that influences dose distribution.

ACKNOWLEDGMENTS

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