Neutron contamination of Varian Clinac iX 10 MV photon beam using Monte Carlo simulation

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Abstract. High energy medical accelerators are commonly used in radiotherapy to increase the effectiveness of treatments. As we know neutrons can be emitted from a medical accelerator if there is an incident of X-ray that hits any of its materials. This issue becomes a point of view of many researchers. The neutron contamination has caused many problems such as image resolution and radiation protection for patients and radio oncologists. This study concerns the simulation of neutron contamination emitted from Varian Clinac iX 10 MV using Monte Carlo code system. As neutron production process is very complex, Monte Carlo simulation with MCNPX code system was carried out to study this contamination. The design of this medical accelerator was modelled based on the actual materials and geometry. The maximum energy of photons and neutron in the scoring plane was 10.5 and 2.239 MeV, respectively. The number and energy of the particles produced depend on the depth and distance from beam axis. From these results, it is pointed out that the neutron produced by linac 10 MV photon beam in a typical treatment is not negligible.

1. Introduction

Nowadays, radiotherapy has become the most powerful tool to treat cancer in many countries. Some new technologies are developed to increase the effectiveness of treatments, both of photon and electron beam. For example, intensity modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT) technique use high energy medical accelerator photon beam by controlling the multileaf collimator (MLC) movement during the treatment to kill cancer without any harming in the healthy tissue surrounding the cancer [1,2]. Generally, the linear accelerator (linac) used for IMRT and VMAT is high energy linac. Neutrons can be emitted from medical accelerator if incident X-ray hits any its materials. This unwanted neutrons are mostly created by photonuclear reactions. High energy photons created in the high energy photon mode of the linac interact with the nuclei of high Z materials inside the accelerator and liberate neutrons [3]. These neutrons scatter throughout the treatment room and reach the patient. As neutrons have high relative biological effectiveness (RBE), even small neutron...
doses may be harmful to the patient [4, 5] and medical staff [6]. In this case, special radiation protection methods have to be implemented in order to prevent patients and medical staff from exposure to it. This study concerns the simulation of neutron contamination emitted from Varian Clinac iX 10 MV photon beam using the Monte Carlo code system. The neutron production process is so complex, and therefore Monte Carlo simulation with MCNPX and PHITS code system was carried out to study this contamination. Many studies have been performed to characterize the secondary neutrons from high-energy linacs using Monte Carlo simulation [7, 8].

The aim of this study is to investigate the neutron contamination in Varian Clinac iX 10 MV photon beam.

2. Methods
Monte Carlo calculation MCNPX version 2.4.0 and PHITS 2.81 Monte Carlo code were used to model photon beams from the Varian Clinac iX 10 MV Photon beam. MCNPX is a well-known general purpose of Monte Carlo code developed at Los Alamos National Laboratories. It extends the transport capability of Monte Carlo program to include 34 particles over a more complete energy range. This range (<150 MeV) of energy can be used to simulate radiation transport of these particles in radiation therapy applications. Figure 1 shows the setup of the simulated geometry for the Varian Clinac iX 10 MV modelled by PHITS.

![Diagram of Varian Clinac iX 10 MV photon beam setup](image)

**Figure 1.** Sketch Varian Clinac iX 10 MV photon beam.

The design of this medical accelerator was modelled based on the materials and geometry of its actual. In this simulation, the optimal initial electron beam parameters were 10.5 MeV in energy. The electron source with a point source was put before the target. The simulated model included the bremsstrahlung target, the primary collimator, the vacuum window, the flattening filter, the monitor ion chamber, the mirror, and the upper and lower jaws. A beam monitoring chamber and flattening filter were accurately modelled due to the fact that they are the main sources of contaminating electrons. This detailed description of the geometry required for the accurate simulation was provided by the
manuafacturer. The electron and photon cut-off energies were set to 0.5 MeV and 0.01 MeV, respectively. Table 1 represents the material of each linac component and its density used in simulation.

**Table 1.** Details of CMs parameters.

| CMs name           | Distance from reference plane (cm) | Materials          | Density (g/cm³) |
|--------------------|------------------------------------|--------------------|-----------------|
| Target             | 0                                  | Copper             | 8.96            |
| Primary Collimator | 5.5                                | Tungsten           | 19.25           |
| Exit windows       | 8.66                               | Beryllium          | 1.85            |
| Flattening filter  | 9.2499                             | Copper             | 8.96            |
| Ion Chamber        | 14.79                              | Kapton and Air     | 1.42 and 0.0012 |
| JAWS Y             | 27.88                              | Blok Tungsten      | 19.25           |
| JAWS X             | 36.63                              | Blok Tungsten      | 19.25           |
| MLC                | 48.185                             | Tungsten           | 19.25           |
| Scoring plane      | 100                                | Water              | 1               |

The MLC are used to create a square field size ($10 \times 10$ cm²) at the isocenter. Up to this point, the simulations included geometries for the MLC and upper jaws and lower jaws that were not quite representative for the Varian machine (the tip of MLC and JAWS not rounded shape). The number of history used in this simulation was $2 \times 10^9$ particles. The F4 and *F4 tallies were used to calculate the fluence profiles, the energy spectra, and the mean energy profiles at the phantom surface. The maximum statistical uncertainty of our results was about 7% for the neutron part and 0.4% for the electron and photon part in the scoring plane. The importance of electron, photon and neutron was set to 1 for each linac component (IMP: E 1, IMP: P 1, IMP: N 1).

3. Results

Figure 2 shows the photon, positron, electron, and neutron spectra calculated by PHITS code system in the target and in $50 \times 50$ cm² the scoring plane (100 cm from target).

![Figure 2. Photon (red), positron (green), electron (black), and neutron (blue) spectra after target and in the depth 100 cm generated by 10 MV Varian Clinac iX 10 MV photon beam.](image)

The neutron energy produced in the target is less than 1 MeV. The neutron with energy more than 1 MeV was produced in the depth 100 cm from target. The electron dominated the particle in the target component module with a maximum energy of 10.5 MeV.
Figure 3 shows the fluence of electron, photon and neutron in x-z plane. The unwanted particles (electron and neutron) give contribution to this photon beam but most of them are scattered to the treatment room. The statistical uncertainties in the simulation depend upon the number of particle histories used to determine the results. In this case the uncertainties are +7% due to the lack of neutron in the scoring plane. Another uncertainty was caused by uncertainties in the photoneutron cross sections. This
systematic uncertainty has resulted in the overall uncertainty in the calculated results of both fluence and energy in the range from *25% to +35%.

Table 2 shows the maximum and minimum energy of neutron produced in some component modules of linac Varian Clinac iX 10 MV photon beam.

**Table 2.** The maximum and minimum energy of neutron in some components of linac.

| Energy (MeV) | Target  | Primary Collimator | JAWS Y | MLC    | Scoring plane |
|-------------|---------|--------------------|--------|--------|---------------|
| Maximum     | 1.778   | 2.818              | 1.41   | 1.512  | 2.239         |
| Minimum     | 0.005   | 0.0028             | 0.0199 | 0.045  | 0.01          |

4. **Discussion**

The linac incident particle was electron with a maximum energy of 10 MeV. In Figure 2, it can be seen that the electron and photon dominated the particles in the target and scoring plane, respectively. The maximum energy of photons in the scoring plane was 10.5 MeV. The number of photons, electrons and neutrons decreased gradually with the depth. The bremsstrahlung process dominated the reaction in the target (Cu with the thickness of 0.508 cm) that produced gamma. The photon passed the primary collimator, vacuum window, flattening filter, ion chamber, JAWS Y and JAWS X and multileaf collimator. The bremsstrahlung radiation through vacuum window was modified by a flattening filter. The energy fluence flattens after the flattening filter (Figure 3 (a)).

Figure 3(b) and (c) show the unwanted electron and neutron produced by the linear medical accelerator. The electrons and photons produced in high energy linacs may undergo elecneutron (e,e’n) interactions and photoneutron (γ,n) interactions, respectively. Both types of interactions produce neutrons as by-products. Elecneutron production is 100 times less probable and therefore neglected in the simulations. Photoneutron production is governed by the neutron separation energy and by photoneutron cross-sections. Figure 3(c) shows the neutron fluence in x-z plane. Most of the neutron is scattered in the treatment room and this neutron effect was not good for medical staff.

Table 2 below shows that the energy of neutron changed depending on the distance between linac component, the target, and the distance to the beam axis. This results have a good agreement with another study that the energy and amount of neutron decreases gradually from the center of the field [9].

5. **Conclusion**

From these results it is pointed out that the neutron produced by linac 10 MV photon beam in a typical treatment is not negligible. Therefore, this new system, consisting of Monte Carlo simulation and spectral measurements, represents a reliable approach to evaluate the leakage neutron field and to optimize the treatment plan.

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Acknowledgements
The authors thank Varian Medical Systems for providing technical data of linear accelerator to be modelled with Monte Carlo. This study was fully supported by Hibah Disertasi Doktor 2016 and Kerjasama Luar Negeri Dikti, Ministry of Education Indonesia 2016.