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Simulation of neutron production in linac radiotherapy using the monte carlo fluka-flair method

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ABSTRAK

The use of high-energy photon beams in radiotherapy aims to increase the effectiveness of the radiation beam so that it can reach tumors that are deeper than the surface of the skin. However, linac aircraft operated above 8 MV can cause photonuclear interactions. Neutrons, which are highly avoided in medical physics, can be generated from the interaction of high-energy photons with materials with high atomic numbers (Z) in linac heads. The study focused on simulating the production of linac 10 MV aircraft contaminant neutrons using Fluka-Flair software based on the Monte Carlo method to find out where the contaminant neutrons come from and their dose contribution to the water phantom. The simulated linac aircraft is a linac head consisting of target components, primary collimator, Flattening filter, ion chamber, Secondary Collimator, and Phantom. The simulation results show that neutrons are generated at the target component, primary collimator, Flattening filter, ion chamber, secondary collimator, and water phantom. Tungsten is the target material with the most excellent 55,08% neutron fluence due to its highest atomic number, Primary Collimator 23,45%, Flattening Filter 10,67%, Ion Chamber 7,58%, Secondary Collimator 3,07% and Phantom 0,15 %.

Keywords: flair, fluence neutron, fluke, linac, photonuclear.

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INTRODUCTION

Radiotherapy is a modality that is widely used for the treatment of cancer cells. Radiation administration is expected to slow the growth of cancer cells and does not affect surrounding cells. Therapy with this radiation can be carried out in two modes the photon mode and the electron mode. The difference is in the radiation source used to treat the patient.

One of the radiotherapy tools or machines is the Linac machine (Linear Accelerator), a machine that can accelerate the motion of particles. Linac can accelerate the movement of electron particles with the potential difference that exists in the linac machine. Suppose the electron mode is to be used. In that case, the electron particles will be accelerated and scattered on one of the Linac materials and arranged according to the geometry of the target to be exposed to the electron radiation. Meanwhile, if you choose the photon mode, then the accelerated electron particles will be pounded into the target material from Linac to produce a photon beam. This photon beam will be used for therapy to patients. The maximum photon energy produced in the Linac-type Siemens Primus machine is 14.5 MeV. The advantages of using a high-energy photon beam include deepening the maximum dose area, reducing the dose on the surface, and reducing the scattering dose in healthy cells, but using a high-energy photon beam is an essential issue in radiation protection systems because there is a possibility that Linac will produce neutron particles, Giving neutron particles to patients is an unwanted dose of radiation, this dose of neutron radiation can cause secondary cancer cells. For Photon beams with energies greater than 10 MeV, Linac will produce neutrons due to photon interactions with materials that make up Linac for materials with high atomic numbers. Even photons with an energy of 7 MeV can interact to produce neutrons. X-ray radiation beam with an energy of 10-18 MV can produce neutrons with an energy range of 1-2 MeV. Neutrons are produced from photonuclear interactions. Neutron particles will be produced when photons come with energy more significant than the threshold energy of photonuclear interactions. The threshold energy limit depends on the material's atomic number subjected to photon radiation. The threshold energy limit is around 8 MeV if the atomic number is high. If the atomic number is low, the energy threshold will be higher, for example, 16 MeV for oxygen and 18 MeV for carbon.

As we know that particle radiation cannot be seen directly by the eye, therefore to find out whether the particle radiation that comes out of the Linac is only particle radiation that can be received, such as an electron, positron, and photon particles, and there is no unwanted particle radiation such as particles neutrons, one way to find out is to do a simulation first, radiotherapy planning is done by simulation. Monte Carlo is one of the most accurate methods for simulating particle transport. The difference in Monte Carlo simulation results with experimental data is less than 2% in the flat area of the dose profile, deviation of 1.07% PDD Monte Carlo and experiments, and even less deviation than 0.1% PDD at a depth of 10 cm. These data show the accuracy of the Monte Carlo method in simulating particle transport, even though using different software such as EGSnrc, MCNPX, and FLUKA. Therefore, the aim of this research is to simulate the production of neutron particles in Linac using the Monte Carlo method in FLUKA and FLAIR software to find out which components of Linac materials contribute the most to the production of neutron particles.

RESEARCH METHODS

This research was conducted in two parts, the first was the Linac design process, focusing on the material components making up the Linac head, and the second was a simulation. In the design process for the Linac head, the geometry, material, and size information refers to the Linac example in the photon mode BEAMnrc software. This was done due to limited direct Linac head specification information. Several papers indirectly write down specification information for the Linac head, such as geometry and size. Still, not all the material components of the Linac head are written down. Ultimately, you must combine some of the information from the papers to design the Linac head. Combining these specifications becomes difficult when validating because the specifications are obtained from several papers. Therefore the author takes the Linac head specifications in the BEAMnrc software directly so that in the validation process, they can now compare the results using FLUKA- FLAIR and BEAMnrc software. This validation can be done as a separate research topic. After the Linac head specifications were obtained, the Linac head and phantom with a size of 40x40x40 cm^3 began to be designed using FLAIR software. The FLAIR software was integrated with FLUKA software and continued designing a phantom filled with water material. Here are the Linac head specs.

Table 1. Linac head specifications

Linac head components	Material	Atomic number
Target	Tungsten	74
Primary Collimator	Iron	26
Flattening filter	Copper	29
Ion chamber	Air	7,262
Secondary collimator	Copper	29
Phantom	Water	3,333

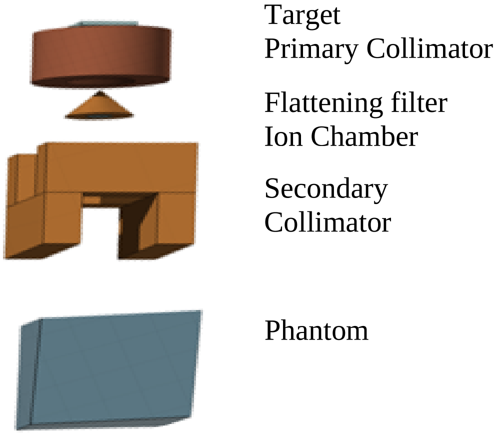

Figure 1. Linac geometry models

After the Linac and phantom heads have been designed, proceed to the second part, the simulation process. Some of the parameters used in this simulation include the initial particles used are electron particles with an energy of 10 MeV, photon mode, and 100 cm SSD. The simulation was conducted at the Physics Modeling Laboratory of the Integrated Laboratory Building, 3rd floor, Intel Xeon(R) CPU E5-2609 @ 1.7 GHz 16 Core computer. The initial number of electron particles used is 8×10^9, simulated in parallel cores, using eight computer cores simultaneously to reduce the required simulation time. The quantity to be analyzed is the fluence of neutron particles on each Linac head and phantom material component.

RESULTS AND DISCUSSION

Based on the data, the time needed to simulate the initial 8×10^9 electron particles is 237,5 hours or ten days. The average statistical uncertainty of the simulation results on the target material component is 0,58%, Primary Collimator 0,77%, Flattening Filter 0,9%, Ion Chamber 0,94%, Secondary Collimator 1,34% and Phantom 13,32%, the average statistical uncertainty of all components is 2,98%, the statistical uncertainty of the simulation should be below 1%, as a comparison of the 7% statistical uncertainty that has been carried out by other research by simulating 2×10^9 initial electron particles so that it can be said that 2,98% is a good result. The number of initial particles used is one factor affecting the statistical uncertainty in the simulation. The greater the number of initial particles used, the smaller the resulting statistical uncertainty. The fluency of neutron particles in each material component that makes up the Linac and Phantom heads can be seen in the following figure.

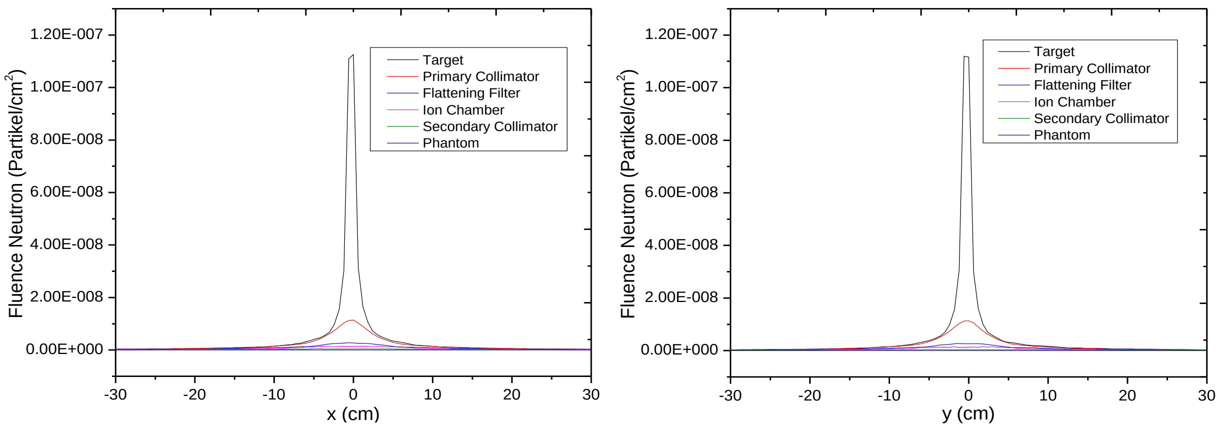

Figure 2. Neutron fluence in the x and y directions for the linac head

Based on Figure 2, the neutron fluence on the x-axis and y-axis has the same pattern. The number of neutron particles passing through the target component is the largest and continues to decrease when passing the next component. Neutron production can occur through photonuclear interactions. When a photon interacts with the atomic nucleus of the material, it will produce a neutron particle. The energy of the incoming photon must be higher than the binding energy between the last neutron and the atomic nucleus. For example, a photon interacting with a carbon atom must have an energy of 5 MeV and 20 MeV photons for Helium atoms. The photon energy limit for photonuclear interactions to occur depends on the atomic number of the material. For materials with a high atomic number, the energy limit is around 8 MeV, while for materials with a low atomic number, a higher energy limit is required so that materials with a high atomic number have an interaction probability. Photonuclear is fifty times larger than that of low atomic number materials. Therefore, based on the data in table 1, Tungsten is the target material and has the largest 55,08% neutron fluence because it has the highest atomic number. This is in accordance with the results, Primary Collimator 23,45%, Flattening Filter 10,67 %, Ion Chamber 7,58 %, Secondary Collimator 3,07 %, and Phantom 0,15 %. In other material components, the neutron fluence continues to decrease even though the atomic number of some materials has also increased. The atomic number of the secondary collimator material is higher than that of the primary collimator material. The photons that enter the secondary collimator material are different from those that enter the primary collimator. Theoretically, it can be explained that the photon energy that enters the secondary collimator material is smaller than that of the primary collimator material. This part can be predicted as the cause of the difference so that it can be used for further research.

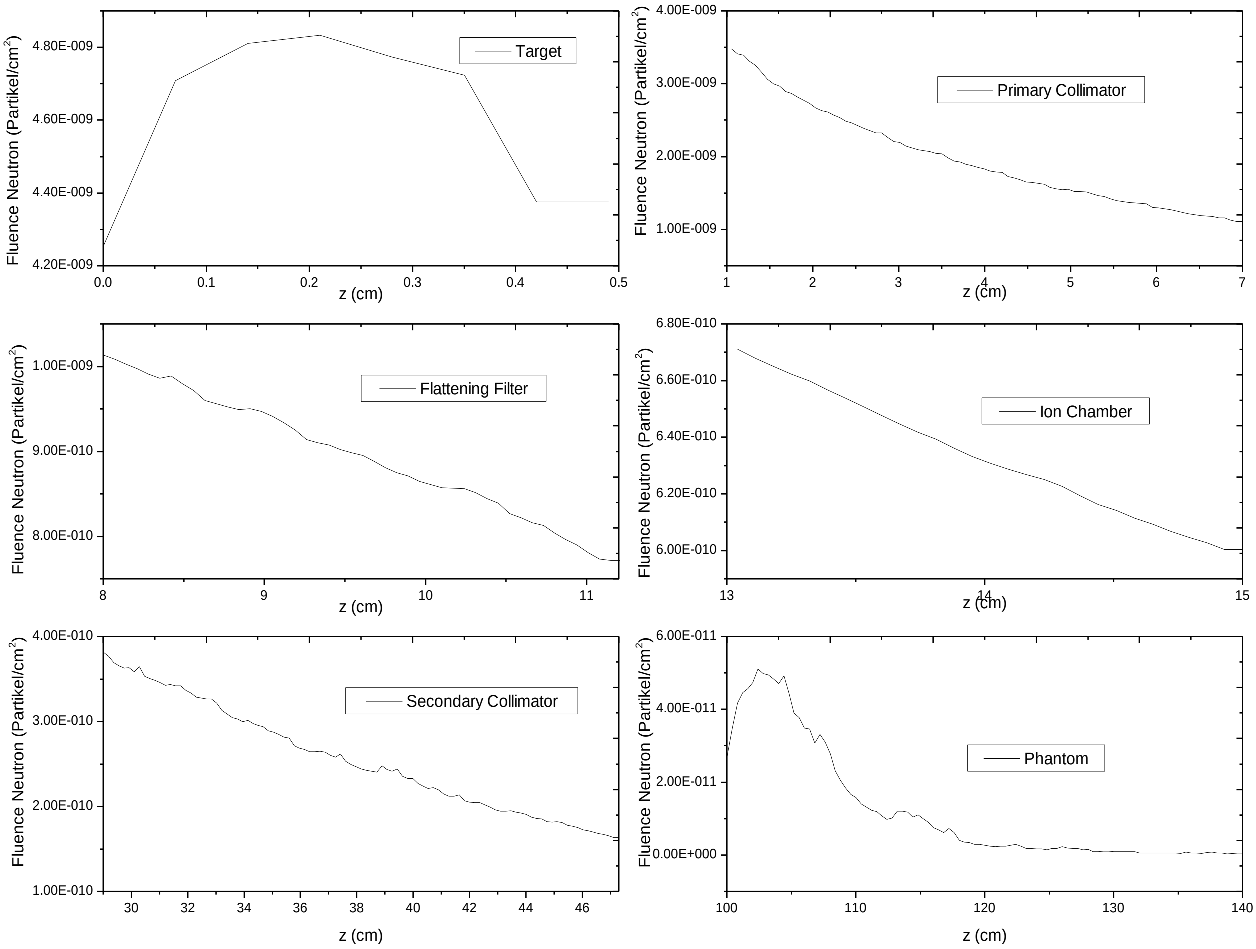

Figure 3. Neutron fluence in the z direction for the linac head component

In figure 3, the neutron fluence in the Z direction also has the same pattern as the X and Y axes, the neutron fluence on the target material has the highest value, and the fluence decreases as the material gets deeper. These results are from research conducted by for Tungsten materials. At the initial surface, the number of neutrons increases and decreases as it gets deeper. The neutron fluence of the phantom material, at a depth of 100 cm to 100,24 cm at the beginning, has increased. This is because there is air material between the secondary collimator and the phantom, resulting in an increase in the fluence of neutrons on the surface of the phantom.

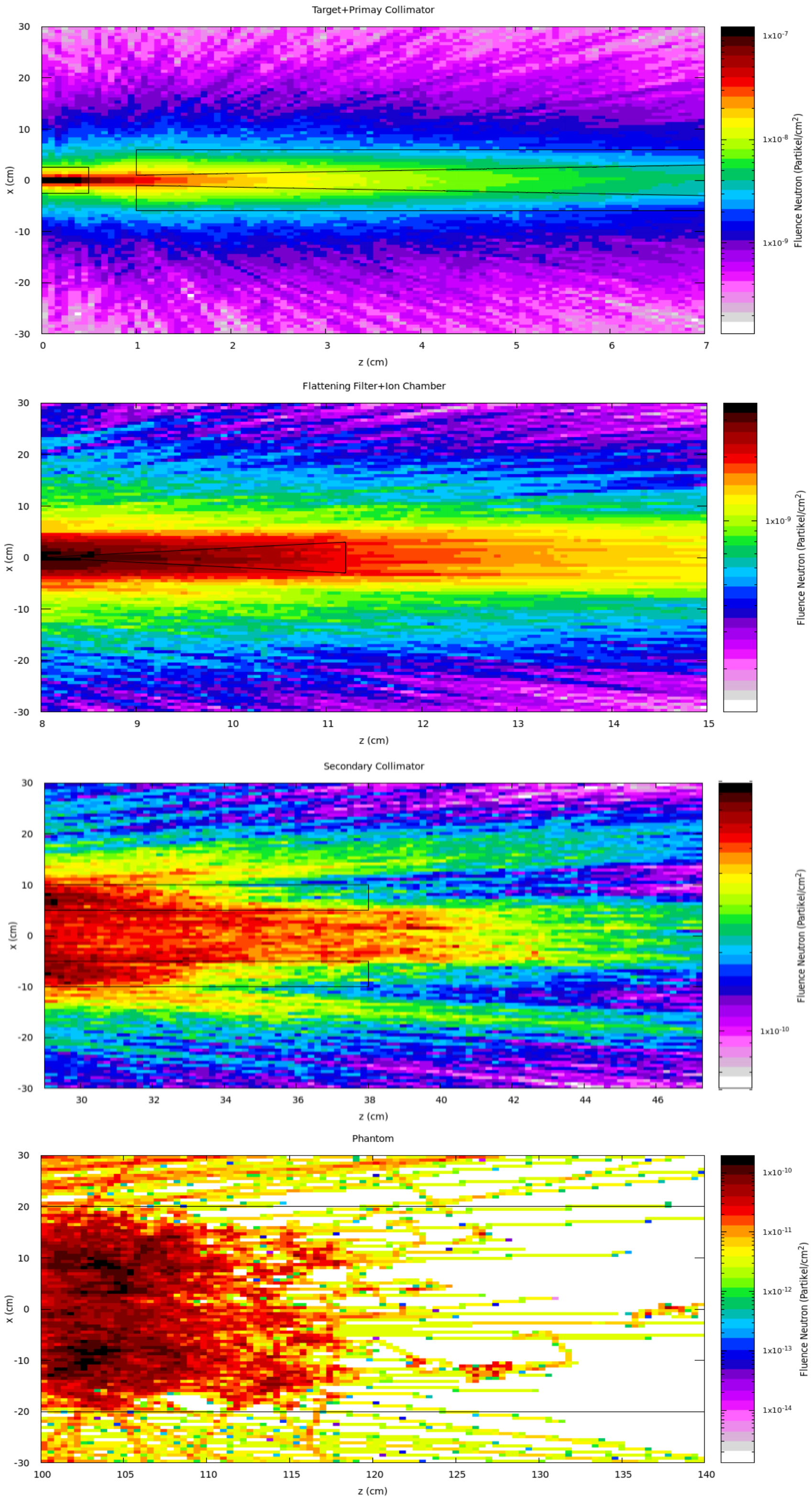

Figure 4. The z-direction 2d fluence neutron distribution of the linac head material components

Figure 4 is a 2D view of the distribution of neutron particles for each material component making up the Linac head. Several distribution data are combined into one view, like the Target with the Primary collimator. The target number of neutron particles is greater than that of the primary collimator, as well as the following 2D distribution images. It can be seen that each image has a black color at the beginning of each material surface. This illustrates that the number of particles is more significant at each initial material surface and decreases with increasing depth on the Z axis.

CONCLUSION

A simulation of neutron production has been carried out on the Linac head using FLUKA-FLAIR. The intended neutron production can be reviewed based on the number of neutron particles penetrating each Linac head material component. The Target component has the most significant contribution to the production of neutrons because it has the highest atomic number.

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