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RESEARCH ARTICLE

THE EFFECTS of DIFFERENT RATIO for GADOLINIUM (GD) and TUNGSTEN (W) on NEUTRON CONTAMINATION CAUSED by MEDICAL LINAC COLLIMATOR

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ABSTRACT

The linear accelerators (LINACs) produce high-energy X-rays and electron beams. The interaction between material and radiation is the basis of radiotherapy for the treatment of cancer patients. Neutron contamination is produced in electron beams of medical LINAC by the contribution of the primary and secondary collimators in LINAC as external beam radiotherapy. The photoneutrons produced are easily distributed and spread into the clinical region. As a result, it is recommended that treatment planning be carried out in the patient's tumor volume as well as places outside of this volume. The primary and secondary collimators were found to contribute roughly 52 and 30 percent of the neutron contamination, respectively. The aim of paper is to determine the neutron dose contamination in a LINAC from various materials. Using the Geant4-based Architecture for Medicine-Oriented Simulations (GAMOS) and TALYS 1.95 algorithms, the effects of different material ratios in secondary collimators, such as Gadolinium (Gd) and Tungsten (W), on neutron contamination have been investigated.

Keywords: *Medical LINAC, Photoneutron, Secondary Collimator, Neutron Contamination, GAMOS, TALYS 1.95*

1. INTRODUCTION

Immunotherapy, surgery, chemotherapy, radiotherapy, and/or a combination of these treatments may be used to treat cancer. One of the cancer therapies that employs high doses of radiation to destroy cancer cells and shrink tumors is radiotherapy. One of the most essential procedures utilized in the treatment of many types of cancer is radiotherapy. It is based on the interaction of ionizing radiation with tumor cells and the biological consequences that result in malignant tissue management and treatment [1].

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The linear accelerators (LINACs) are machines that produce high-energy X-rays and electron beams For the treatment of cancer patients, Radiotherapy works by interacting with matter, namely the electrons that surround the nucleus in cells. Ionizing radiation is used to break the DNA of the cells during treatment. As a result, the interaction between radiation and matter translates radiation physics into cancer treatment in the clinic [1].

The treatment method used in cancer treatment is the treatment with X-rays obtained by striking the electrons accelerated in the LINAC to the tungsten (W) target. Linear accelerators are used in the treatment of many types of tumors with the photons and electrons they produce at different energies [2,3]. The collimator designs of LINACs are directly related to the semi-shadow formed at the radiation field edge. Collimation system, dose reduction between 20% and 80% at the radiated edge determines the amount of their penumbra. While it is the same for the x and y collimators that form the field edges for some LINAC heads [4]. X-rays travel through the medium, they interact with the electrons in the medium and cause ionization.

The photoneutrons formed can be scattered and spread out from the LINAC head and into the treatment room. As a consequence, an additional neutron-induced dose occurs in the tumor volume of the patient [5]. In addition to the dose that will occur in the patient, it will cause a significant amount of biological side effects in the patient due to the high linear energy transfer of the neutron [6]. This undesirable dose will increase the risk of secondary cancer in the patient [7]. The creation of a radiation protection protocol suitable for the device used can be created by calculating the neutron dose that patients and employees will receive. In the literature, using the Monte Carlo (MC) based code, the effect of using different composite materials and field sizes with high neutron absorption cross-sections in secondary collimators on neutron dose equivalent (NDE) is also investigated [8,9].

GEometry ANd Tracking 4 (GEANT4) has recently been applied in a variety of disciplines, including high-energy physics, medical physics, and space sciences. GEANT4's modularity allows users to load, utilize, and modify only the components they require. The physics models utilized may be easily understood because to the GEANT4 design and accessibility [10]. Thanks to its sophisticated scripting language, the Geant4-based Architecture for Medicine-Oriented Simulations (GAMOS) is a GEANT4-based MC code meant to be the most widely operable in medical physics applications without the requirement for C++ coding [11].

Our previous study was evaluated the contribution of photoneutron contamination in LINAC by the different composite materials. We compared the condition experimental results to MC Fluka code simulations, and the effect of field size and distance from the isocenter on NDE was İnvestigated [12-14].

The present study aims to calculate the neutron contamination of LINAC via 18 MeV in the case of various materials by using GAMOS and TALYS 1.95. Using the GAMOS and TALYS 1.95 programs, the effect of using different composite materials with high neutron absorption cross-section in secondary collimators on NDE was demonstrated.

2. MATERIAL AND METHOD

We used to determine the new material used on the secondary collimator via TALYS 1.95 code. TALYS is commonly used by researchers in nuclear reaction calculations. Radioisotope production

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cross-section calculations [15-17], astrophysical[18], level density model calculations [17, 19], photoneutron reactions [16] are some of TALYS's capabilities. $natGd(\gamma,n)$ and $natW(\gamma,n)$ reactions cross sections have been calculated to compared neutron production of two materials. In addition to photoneutron reactions, neutron capture reaction cross-sections of both elements have been computed to investigate the absorption of neutrons caused by the primary collimator. Reaction cross-section calculations have been performed by using the Two-Component Exciton Model [20]. Constant Temperature Fermi Gas Model [21] has been selected as level density model whereas Kopecky-Uhl Lorentzian Model [22] has opted for gamma-ray strength function model.The Medical LINAC head geometry has been shown, and 18 MeV spectrum data was used in the simulations in Fig. 1. The detector, which measures 50x50x0.5 cm^3, is placed at a distance of 100 cm from the source skin.

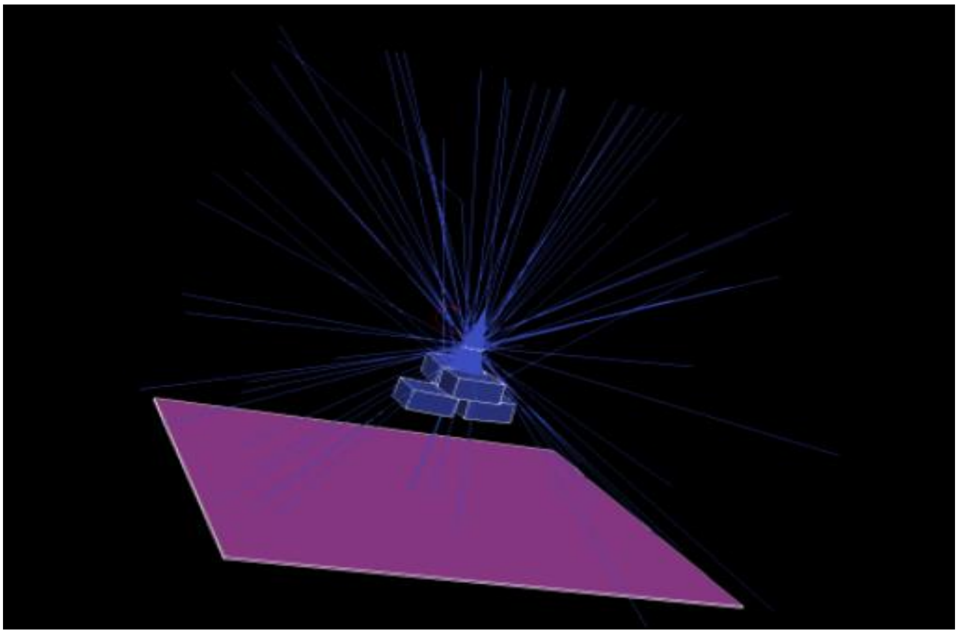

Figure 1. The geometry of the Medical LINAC.

GAMOS 5.1.0 version installed on Linux Mint operating system was used. The geometry used in simulation consists of the point source, tungsten flattening filter, x and y jaws. After passing the 18 MeV cone photon, flattening filter, and jaws, it reaches the detector placed away from the source distance of 100 cm to read the surface flux. The physics package used in the simulation was the G4QGSP_BIC_HP package. While scoring, all neutrons reaching the surface were counted using surface flux and neutron filter. While all physical processes were included in the scoring, variance reduction techniques were not used. The number of 10^7 photons, which gave sufficient results, was used to increase the accuracy of MC calculations and to generate a low statistical error. The calculation time for each simulation took approximately 20 hours, and parallel calculation was not used. W materials doped with Gd in different proportions were created in Table 1.

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Table 1. The different ratio for $W(\gamma,n)$ and $Gd(\gamma,n)$ density and density values.

Material	W%	Gd%	Density (gr/cm^3)
100%W0%Gd	100	00	19.30
90%W10%Gd	90	10	18.16
80%W20%Gd	80	20	17.02
70%W30%Gd	70	30	15.88

3. RESULTS AND DISCUSSION

The effect of different materials in secondary collimators on neutron contaminations were investigated in this paper. First, the photon spectrum at 18 MV, which is given in Fig. 2., has been used in GAMOS simulations. Photon per MeV per incident electron is a maximum of approximately 1 MeV.

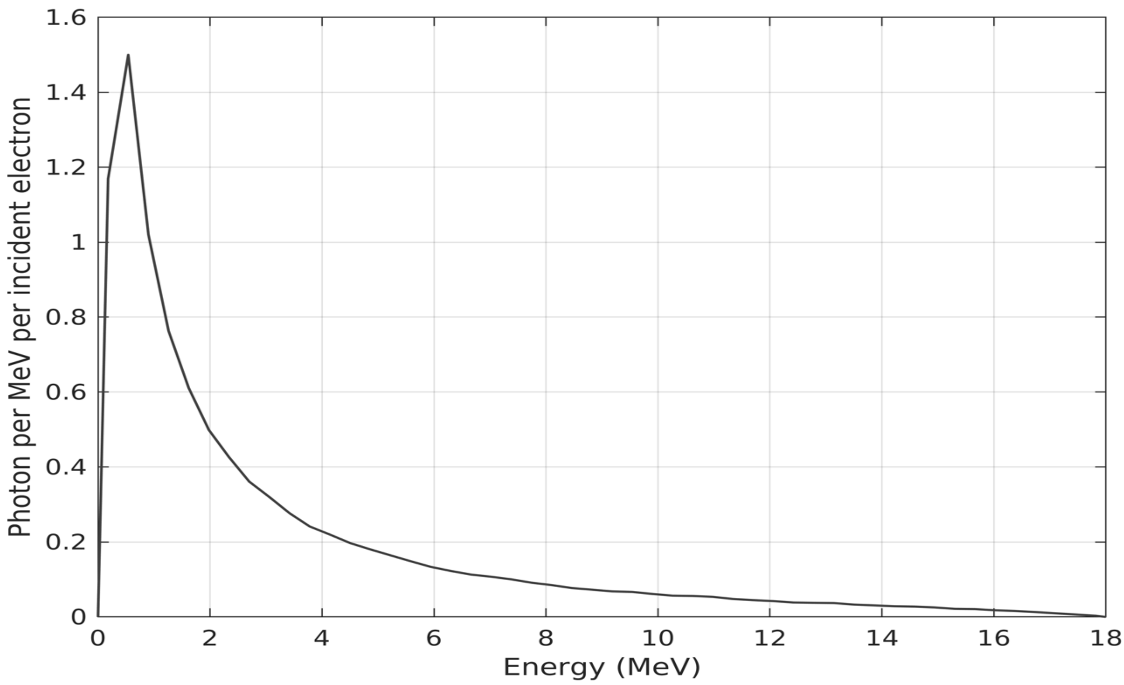

Figure 2. Photon Spectrum at 18 MV.

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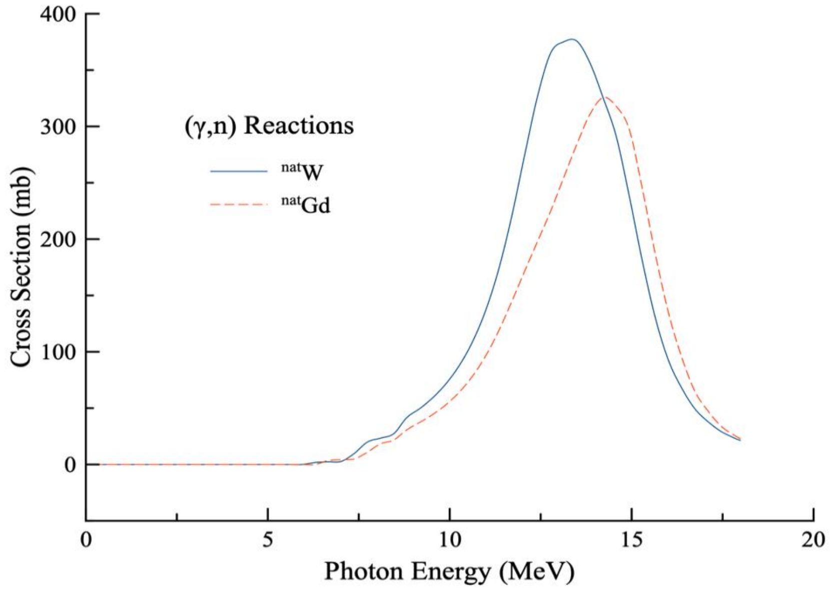

Figure 3. Comparison of $W(\gamma, n)$ and $Gd(\gamma, n)$ reaction cross-section calculations.

After the photon spectrum at 18 MV, TALYS 1.95 code has been used for selecting candidate materials. Photon energies, calculated via GAMOS, have been used as energy inputs on TALYS 1.95. TALYS 1.95 calculations have been divided into three steps. Then, photoneutron reaction cross-sections of $natGd(\gamma, n)$ and $natW(\gamma, n)$ have been calculated to compare the probabilities of two reactions in Fig. 3. The maximum cross-section of $natW(\gamma, n)$ is 375.72 mb whereas it is 325.621 mb. This result supports that the use of Gd can reduce neutron contamination caused by secondary collimators.

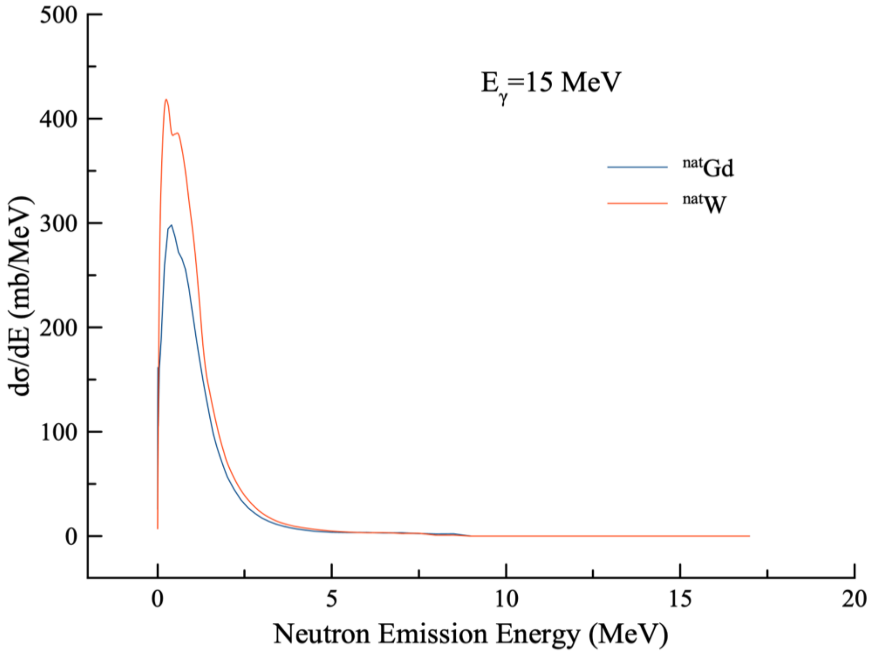

Figure 4. $W(\gamma, n)$ and $Gd(\gamma, n)$ calculations at 15 MeV photon energy.

Then neutron energy spectrums of $natW(\gamma, n)$ and $natGd(\gamma, n)$ reactions have been calculated and presented in Fig. 4. Photon energy has been chosen 15 MeV, because approximately at this photon energy $natGd(\gamma, n)$ reaction cross-section is maximum. It can be found that the neutron energy spectrum of both reactions is equal but have different possibilities. Fig. 3 and Fig. 4 have shown Gd can be reduced neutron contamination caused by secondary collimators. However, it is well known that neutron contamination caused by primary collimator has a 52% ratio.

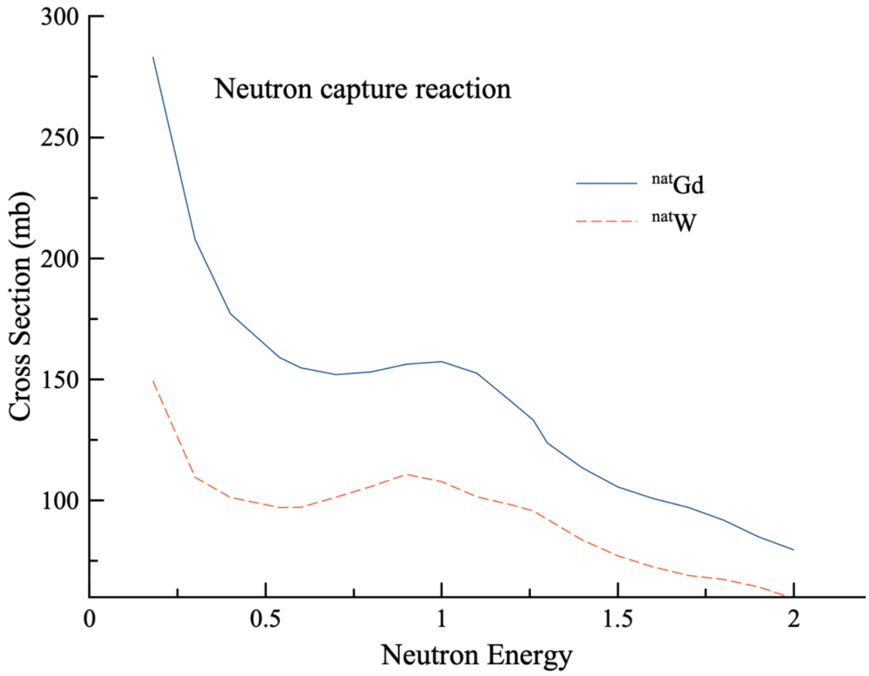

Figure 5. Comparison of $W(\gamma,n)$ and $Gd(\gamma,n)$ reaction cross-section calculations for neutron capture reactions.

We have focused on neutron capture cross-sections of both elements. The comparisons of neutron capture reaction cross sections have been shown in Fig. 5. It is determined that neutron capture reaction cross-sections of Gd are higher than W's. Consequently, it can be speculated that Gd can stop neutrons caused by collimators.

After determining the used Gd on the secondary collimators, GAMOS simulations have been performed for different Gd ratios which are given in Table 1. Total neutron flux has been obtained for this size; 0x0 cm^2, 10x10 cm^2, and 40x40 cm^2. Total neutron fluxes through the size of the different fields and Gd ratios have been presented in Table 2.

Table 2. The neutron flux (particle per cm^2) for different material compositions of secondary collimators.

Field size (cm^2)	Ratio of W/Gd			
	100/0	90/10	80/20	70/30
40x40	6.4 E-08	5.9 E-08	4.8 E-08	3.7 E-08
10x10	4.9 E-08	4.7 E-08	4 E-08	3.6 E-08
0x0	4.6 E-08	4.5 E-08	4 E-08	3.7 E-08

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In 0x0 cm^2 field size total neutron flux of original LINAC whose secondary collimators consist only W, is 4.6 $\times10^{-8}$ particle/cm^2, whereas 4.5 $\times10^{-8}$, 4 $\times10^{-8}$ and 3.7 $\times10^{-8}$ particle/cm^2 for %10, %20 and %30 Gd, respectively. As can easily be seen in Table 2, Gd doped has been reduced neutron contamination at 0x0 cm^2 field size. For 10x10 cm^2 field size, neutron flux has been found 4.9 $\times10^{-8}$, 4.7 $\times10^{-8}$, 4 $\times10^{-8}$ and 3.6 $\times10^{-8}$ particle/cm^2 for 100%, 90%, 80% and 70% W, respectively. As 0x0 cm^2 field size, neutron contaminations have reduced on 10x10 cm^2 field size in Table 2. The last field size investigated in this paper is 40x40 cm^2. Neutron flux of secondary collimators which consist of W has been computed 6.4 $\times10^{-8}$ particle/cm^2. However, neutron fluxes of Gd doped secondary collimators have been found 5.9$\times10^{-8}$,4.8 $\times10^{-8}$ and 3.7$\times10^{-8}$ particle/cm^2 for 10%, 20% and 30% Gd respectively in Table 2.

There are several similar studies evaluating neutron contamination dose in the case of different materials in collimators in LINACs [7, 12, 13]. LINACs are the most widely used medical device for external beam radiation treatments for cancer [1]. The calculation of photoneutrons in LINACs has become important nowadays. The use of Monte Carlo methods in computations, on the other hand, provides more precise data concerning photoneutron properties in radiotherapy [8,10,11]. The goal of this research was to reduce neutron contamination caused by a secondary collimator. As a result, collimators and flatting filters were simulated to examine neutron contamination generated by the secondary collimator using the GAMOS 5.1.0 and TALYS 1.95 codes for Medical LINAC.

Gd and W materials used in different proportions in the secondary collimator changed the neutron flux. Consequently, the contribution of the neutron dose is reduced in the total dose due to the Gd neutron capture is more than W. As a new material, Gd, the simulation was carried out in high dose using GAMOS. The results of these measurements provided important feedback on material development and the dose contribution of Gd and W in irradiation was determined comparatively at different rates

4. CONCLUSION

The generation of neutrons in high-energy photon beams used in radiotherapy is examined in this paper. Our results use W / Gd (70/30) composite material to be an effective method to reduce neutron contamination in secondary collimators. These results have been provided crucial information about unwanted NDE and radiation protection policy for clinic staff and also patients.

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