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Virtual Simulation of Co-60 Gamma Ray Beam Geometry

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Abstract

Radiotherapy forms an essential part in the increase survival and relieve of cancer globally. Tumoricidal dose are delivered to cancerous tumours conformal as practically achievable. Radiation delivery mode, dosimetric verification and quality assurance play a key role in prior to patient treatment. The focus of this study is to present a modality for ensuring good quality control prior to treatment delivery using Cobalt (^{60}Co) source. In the study, absorbed dose to water is computed in a virtual phantom with approximate full scatter conditions with gamma as the radiation source. Monte Carlo Neutron Photon (MCNP) code system was used to simulate the properties of the system geometry of the phantom following the International Atomic Energy Agency (IAEA) Technical Report Series 398 protocol. The research was limited to the use of virtual simulation of water phantom for the Cobalt-60 treatment unit. This work provides information recommended for photon energy according to the medical situation at the radiotherapy facilities in Ghana.

Keywords: Radiotherapy; Monte Carlo; Virtual Phantom; Cobalt-60.

1. Introduction

The amount of radiation dose delivered to the target and surrounding tissues is one of the major predictors of radiotherapy treatment outcome. This could be achieved by conforming the dose distribution to the shape of the intended target whilst minimizing radiation to normal tissues in close proximity.

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It is non-invasive and allows for sparing of normal healthy tissues and dose escalation [1]. A physical phantom or a computational phantom that mimics human anatomical features could be used to derive the irradiation dose inside the body. In *in-vivo* dosimetry with Monte Carlo (MC) could be used as a quality assurance (QA) tool for treatment planning systems (TPS) in therapy. Quality assurance in the radiotherapy treatment planning process is essential for minimizing the possibility of undue exposure [2]. This approach is to monitor the radiation dose in radiation facility, which would serve as a safety measure to estimate the extremity dose to patients during treatment where avoidance of high radiation exposure is the ultimate goal. The IAEA TRS398 protocol used for beam calibration in terms of absorbed dose to water of ^{60}Co was employed. This is because a number of countries still use the Co-60 sources for treating cancers and also the gamma ray source has a significant part of low energy scattered photons, which originates in the source itself or in the treatment head [3].

2. Method

A gamma source of mean energy 1.25 MeV (^{60}Co) was used as the radiation source in the Monte Carlo simulation. A water (H_2O) phantom was used as the reference medium for measurement of absorbed dose for photon beams as recommended by the IAEA code of practice [3]. As the beam incident on the phantom, the absorbed dose varies dependent on the beam energy, depth, field size and distance from the source and beam collimation system [4, 5]. Thus, the modelling of the dose in the phantom considered the variations that affect dose distribution. The field size used was 10 cm x 10 cm and distance from the source was 100 cm. Figure 1 shows the experimental setup of the irradiation geometry used for the determination of absorbed dose to water procedure adopted by IAEA TRS398 in the radiation field.

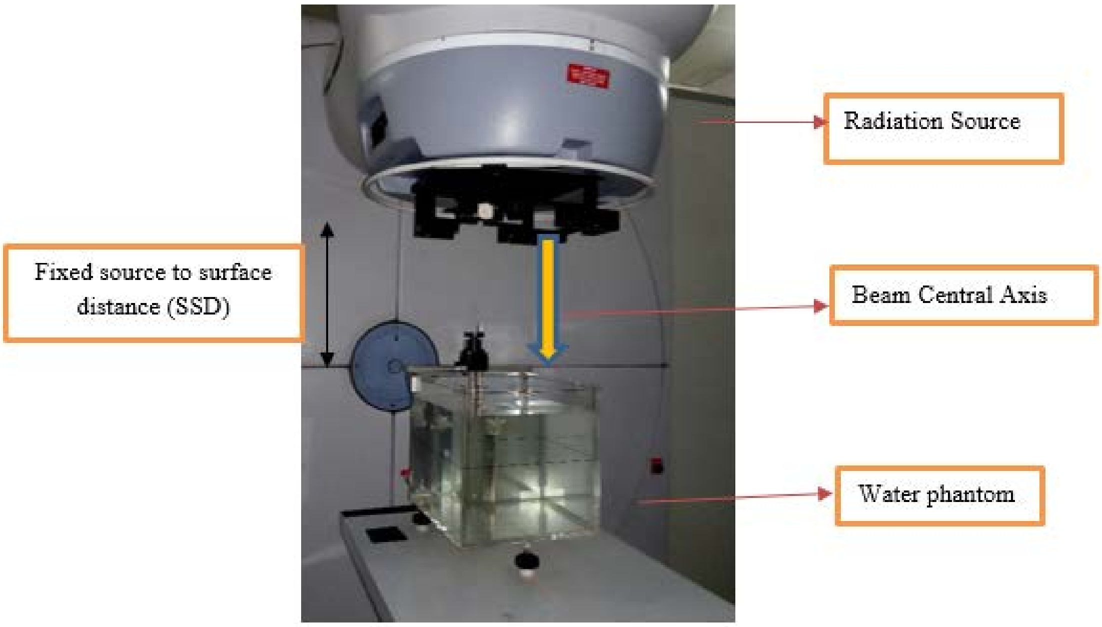

Figure 1: Setup for irradiation geometry for beam calibration

A photon virtual source was used for simulating the arbitrary beam distribution using Monte Carlo code. The MCNP code was used because of its ability to simulate any 3D geometry with precision. The simulated virtual phantom used has the same absorption and scatter properties as water. The code sectioned or meshed the 1000 cm^3 water phantom into 25,000 smaller volumes for which the dose for every volume element (i.e. voxel) could be calculated. The meshing of the phantom were 50x50x10 in x, y and z-planes respectively. The results of the dose in the z-plane were plotted using MATLAB. Figures 2 and 3 shows the 3D and 2D geometric view of the water phantom and the source respectively.

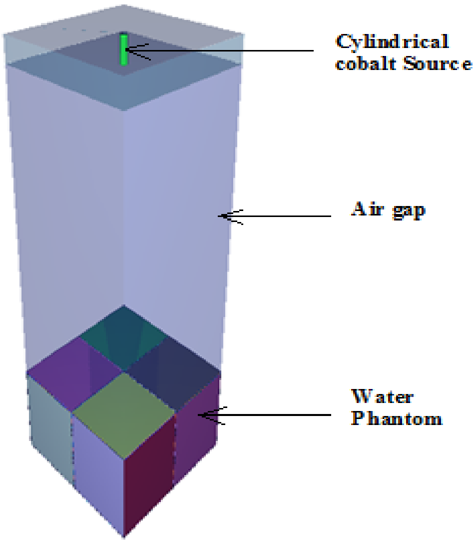

Figure 2: MCNP 3D geometric view of simulated virtual phantom

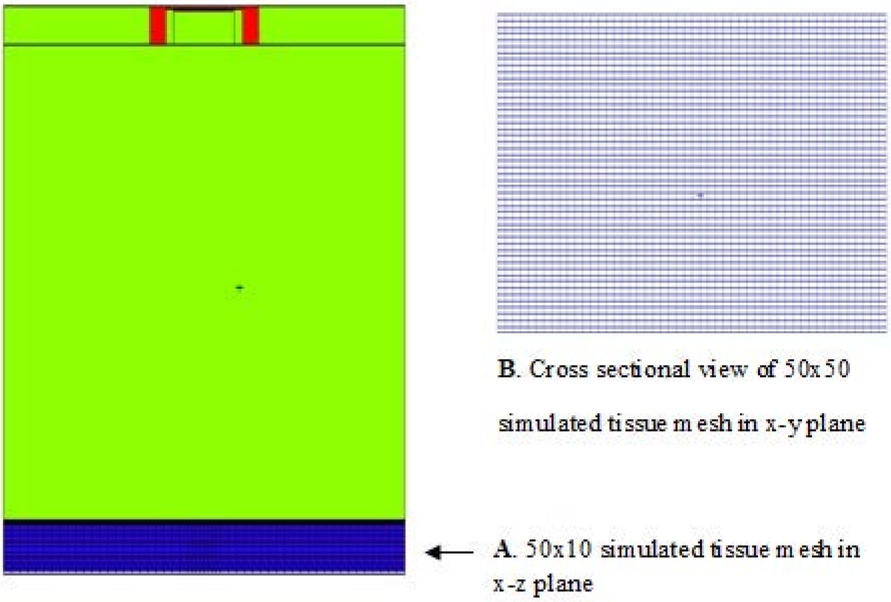

Figure 3: MCNP 2D geometric view of simulated virtual water phantom

Cylindrical geometries were employed for modelling of the source holders while planer geometries were used for the virtual water phantom. The gamma source was specified as surface source, collimated beam and mono-energetic source energies with uniform distribution of radioactive. The gamma source was modelled to emit photons perpendicular to the phantom, parallel in direction of cylinders containing the source in direction of z-plane. These hypothetical source energies were assumed as a disc with 1.5 cm diameter (not to real size) and parallel to x-y plane. Materials constituting the geometric setup were stainless steel, water and air. The elemental composition of the source holder was stainless steel 316L. Whilst that of the water in the phantom constituted hydrogen and oxygen (H_2O) and air was used to fill the gaps in the geometry. The Co-60 source strength at the time of the experimental measurement is used to determine the number of photons emitted by the source per second. The strength of the source and its associated photons together with dose conversion tables in reference according to IAEA TRS398 are used to calculate the dose per each cell.

3. Results and Discussion

Figure 4a-c show the results of the spatial distribution of absorption events of the energy deposited per photon in the z-plane using Matlab. The z-plane was sectioned into ten layers representing the different distance from the surface with each layer having 25,000 voxels.

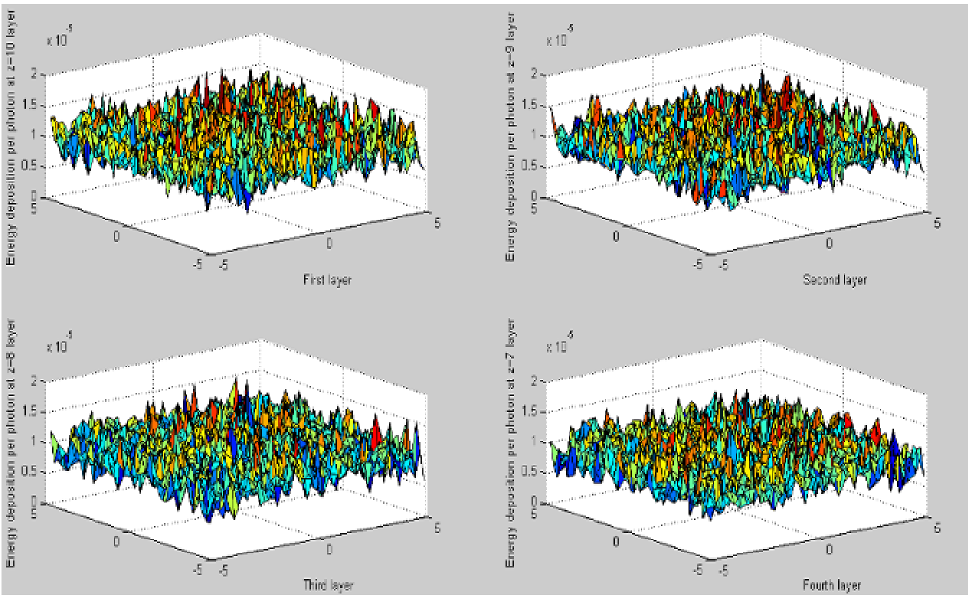

Figure 4a: Energy deposition at the first to fourth layers

From the results, it was observed that the first layer in the MCNP corresponded to the energy deposited per photon at z=10 in the meshed layers in Matlab. The highest peaks in each of the layers shows where the maximum dose was absorbed and acheived. The model computed the dose in each voxel in each layer by transporting several millions of particles based upon probability theory of interacting with the virtual phantom mimicking the patient. This is because radiotherapy involves finding the precise location of a tumour by optimizing the intensity of the radiation and the orientations of the beams shaped to match the plan delineation of the tumour. The simulation model was able to calculate the set of radiation intensities that pass through the phantom for a desired dose distribution mimicking exactly what happens to patient during treatment.

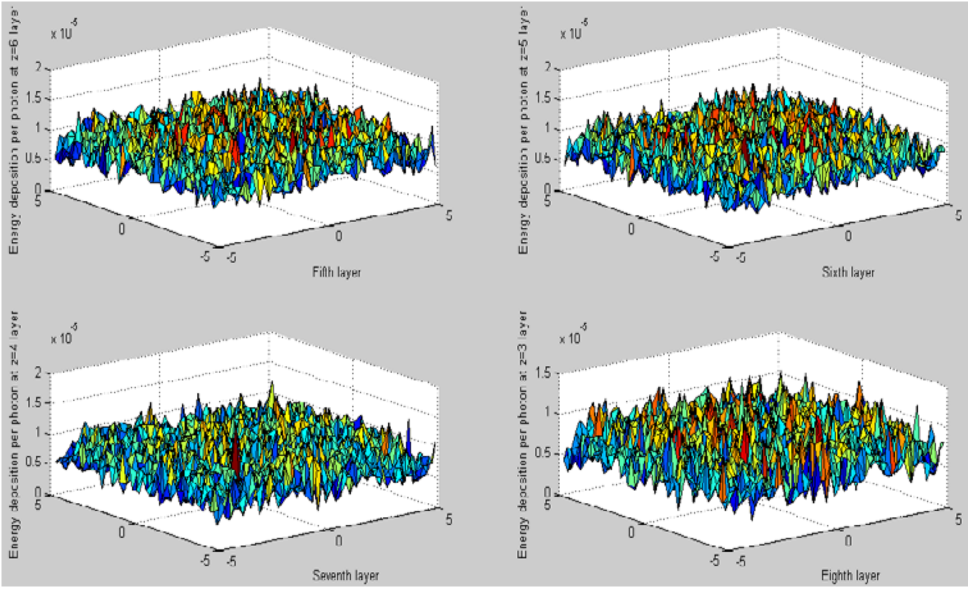

Figure 4b: Energy deposition at the fifth to eighth layers

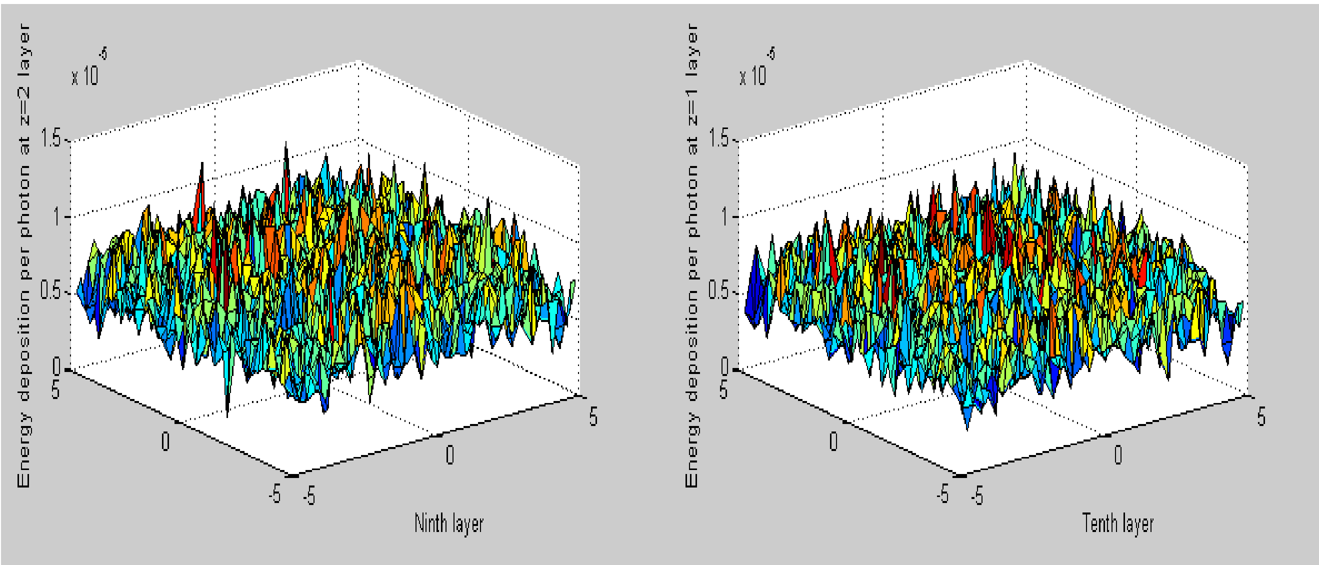

Figure 4c: Energy deposition at the nineth and tenth layers

Based on the results from the simulation a linear response in each layer in the z-plane was determined of which the radiation dose could be accurately estimated. Figure 5 shows a correlation graph which indicates the linear relationship between the response variable (relative absorbed dose) and the predicator (layer number) representing the different distance from the surface within the virtual phantom.

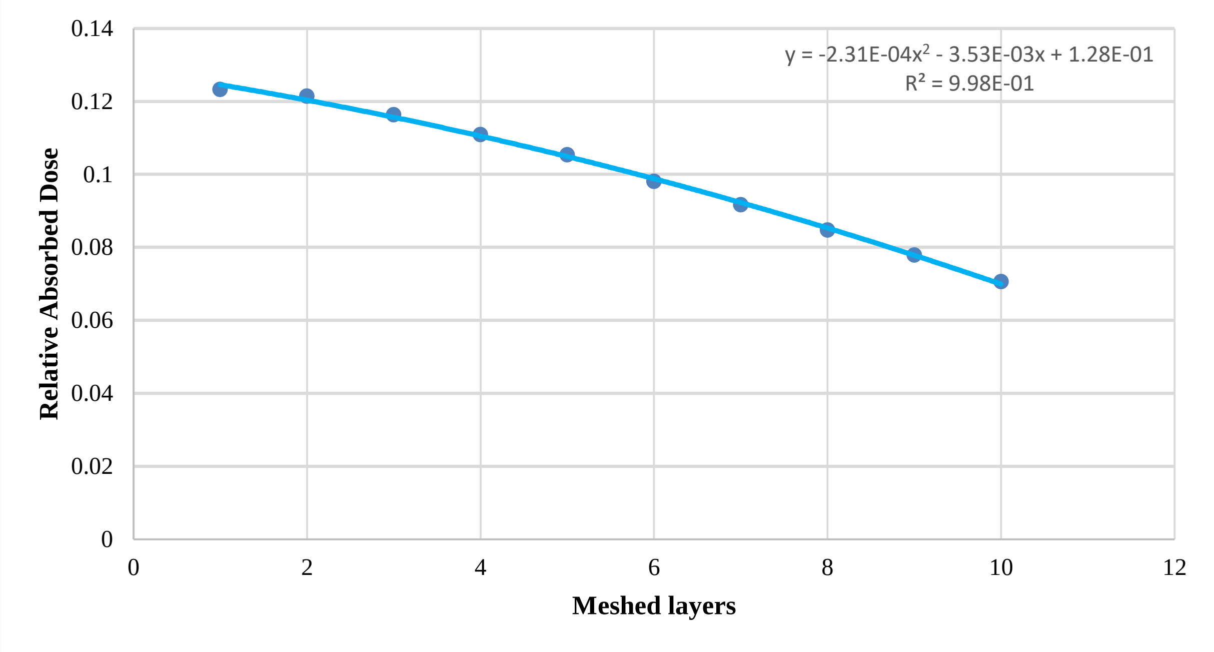

Figure 5: Relative absorbed dose in each meshed layer (tissue)

In Figure 5, the graph gives information on the goodness of the model. The coefficient of determination (R^2) value of 0.998 indicates that the regression line fits the data perfectly with the significance value ($p < 0.050$) less than indicating strong evidence of the model.

Again, the graph shows the estimated regression model of the relationship between the relative absorbed dose in each layer within the virtual phantom using Co-60 teletherapy machine. The layers represents the summation of all the different points located in the different direction within a particular section of the phantom. From Figure 5, the first layer received the highest/maximum absorbed dose while the tenth layer received the lowest dose signifying that, as the photon energy with shorter wavelength passes through the material, the doses at different distances from the surface also changes. The different layers did not absorb the same dose. The non-uniformity of radiation distribution within the virtual phantom might have resulted in the size, location, and composition variations. The absorbed dose was greater at the entrance surface than those deeper within the phantom. Therefore, it could be stated that for a given photon, it absorption dependent on the pentration ability, on the material density to be used and the size of the exposed area. The dose distribution estimated to the various layers within the phantom (virtual) is useful for predicting the therapeutic value in determining the safety treatment outcome for the patient represented by the virtual phantom. It is therefore necessary to precisely know the dose deposited at any point within the body of a patient during radiation therapy as part of dose optimization. The Monte Carlo used for the simulation ensured the estimated dose precision in the therapy of cancer with radionuclides as reported by Sonia and his colleagues [6].

4. Conclusion

The MCNP focused on predicting the dose by calculating the photons that pass through the phantom. The dose values were determined at many points under varying treatment conditions such as field size, source to surface distance and the beam energy. The study provided a theoretical model to predict the dose distribution in each point of the phantom mimicking the tissues in the body during external beam treatment using Co-60 source. The study also demonstrated the advantage of using MCNP as a readily tool that accurately describes the radiation therapy system. Therefore, it is envisaged that with improved algorithms in Monte Carlo, it would be the method simulation technique for radiation therapy.

5. Recommendation

It is recommended that the simulation results should be compared with measured experimental measurements to validate the theoretical results.

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