Monte Carlo study of unflattened versus flattened 18 MV photon beam from medical linear photoneutron source for BNCT applications

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Introduction

Background

• Boron Neutron Capture Therapy (BNCT) is a promising treatment for treating several types of radio-resistant cancers, which includes: brain, neck and liver tumors

• Studies have shown the possibility of using photoneutron emissions from medical linear accelerator as in-hospital neutron source for BNCT

• An accelerator with the flattening filter removed, would increase photon fluence greatly, could deliver considerably higher dose rates

• In this study, the effect of removing the flattening filter from an 18-MV photon beam on photoneutron production was investigated using the Monte Carlo (MC) method

Aims

• the study characteristics of flattened (FF) and unflattened (FFF) photon beam as a source for photoneutron for BNCT

• Photon beam characteristics were studied in terms of: (depth doses, dose profiles, spectra distributions, photon angular distributions, photon x-y position and planner energy fluence)

Materials and Methods

Facilities and Monte Carlo codes

• Beamline/x-ray: MC codes were used to study the photon beam characteristic in this work because they are giving the most accurate results for medical linac simulations.

• MC simulations were carried out on PC computers: Intel Core (i7), 2.2 GHz processor, 8.0 G byte RAM & 320 GB hard disk.

• Experimental measurements were done 18 MV linear accelerator at Trieste Hospital, Italy

BEAmerc medical Linac simulation

• Initially, 18 MV conventional medical linac head was built including: target, primary collimator, flattening filter, ion chamber, mirror and jaws. Another simulation for 18 MV FFF Free has been performed

• The simulations have been run with using 5x10⁷ primary electrons which interact with the accelerator target and produces photon beam

• The collimator was adjusted to produce an output photon beam of 10 x 10 cm² at 100 cm SSD.

• The emitted photons were scored in wider phase space file of 40 x 40 cm² at 100 cm SSD and all the ejected photons were scored including the ones scattered outside the opened field.

Dose calculations in 3-D water phantom by using dosxray

The dosxray MC code was used for calculation of the dose distributions in a 3-D water phantom (Fig. 1). These included calculations of depth dose (DDs), percentage depth dose (PDDs) and cross profile beam.

Experimental measurements

• Percentage depth doses and dose profiles were measured for the 18 MV conventional photon beam for two field sizes 10 x 10 cm² and 20 x 20 cm² at the machine isocenter (100 cm SSD) and were measured with a Photoneutron detector. Beam gantry angle (beam pointing down)

• Electroneter.

• The measurements were carried out in the Blue phantom which configured with OmniPro dosimetry software. The waterproof PTW farmer chamber type 30013 was connected to PTW UNIDOS Universal E.

Results

Comparison of measured and calculated data

Fig. 4. A comparison of dosxray MC calculated percentage depth dose (PDD) versus water phantom measurements for 18-MV photon beam.

Fig. 5. A comparison of MC calculated beam profiles versus water phantom measurements for 18-MV photon beam at 10 cm depth. The 2020% field size curves were scaled by a factor of 1.1 to show the plateau region of all the curves in this figure.

• The statistical uncertainty of MC calculations results was less than 2% for all depths.

• The percentage differences between the measured and the MC calculated PDDs were ranged from 0.233% to 1.019% and ranged from 0.165% to 1.155% for 10 x 10 cm², and 20 x 20 cm² fields, respectively.

• For both profiles, the average flatness difference between the calculated and measured dose on the plateau region was found to be within the acceptance criteria of 3%.

• The average distance between the calculated and measured dose in the penumbra region for all curves was also within the radiotropology acceptance criteria of 2 mm.

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Fig. 6. Comparison of MC calculated PDDs for flattened versus unflattened 18 MV

• In the buildup region, the PDD values for the unflattened beam were have an average percentage difference of 3.044% and 3.864% lower than the flattened beam PDDs for F5 (10 x 10 cm²) and F3 (20 x 20 cm²) respectively in the region in between 0.5 cm and 3.0 cm.

• After F10 cm, unflattened beam became higher than the flattened PDDs and again decreased starting from about 10 cm as clearly shown in Fig. 5-B an average percentage difference of 1.438% and 3.346% for F5 (10 x 10 cm²) and F3 (20 x 20 cm²) respectively in the region in between 10 cm and 30 cm.

• The MC calculated beam profile penumbra for the FFF beam was slightly less (5 cm) than the conventional beam penumura.

• This is mainly due to the flattening filter removal which reduces the scattered radiations

• the photon fluence and relative dose for the FFF beam decrease with increasing the distance from the central axis. The difference in the absorbed dose at an off-axis distance equal to 90% of field size was calculated to quantify the amount of dose reduction near the edge of the beam.

• The dose reduction was 23% and 63% for 10 x 10 cm² and 20 x 20 cm², respectively

Conclusion

• Initially a Varian Clinac accelerator was modeled by beamnsim MC code and then validated by matching the dosxray calculated beam data with corresponding in phantom measurements.

• This followed by a series of MC simulations for investigating photoneutron beam characteristics and for photoneutron productions.

• Flattened and unflattened photoneutron spectra have been simulated using beamnsim MC

• Commonly the FF absorbs low-energy photons generated in the target and primary collimator and act as low energy filter.

• As the FF was removed, low-energy photons can reach the phantom surface and so contribute to the treatment beam.

• However, the energy spectra for the unflattened beam was softer than the flattened beam.

• The FFF medical Linac can give more directed photons beam in comparison with conventional linac.

• The results showed that the FFF Linac produces higher photon fluence and more forward directed photon beams compared with the conventional linac. Therefore, the FFF Linac was selected for photoneutron production through the photoneutron reaction.

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Flattened and unflattened photon beam comparison

Fig. 8. A comparison of MC calculated PDDs for flattened versus unflattened 18 MV photon beam. In the buildup region, the PDD values for the unflattened beam were have an average percentage difference of 3.044% and 3.864% lower than the flattened beam PDDs for F5 (10 x 10 cm²) and F3 (20 x 20 cm²) respectively in the region in between 0.5 cm and 3.0 cm. After F10 cm, unflattened beam became higher than the flattened PDDs and again decreased starting from about 10 cm as clearly shown in Fig. 5-B an average percentage difference of 1.438% and 3.346% for F5 (10 x 10 cm²) and F3 (20 x 20 cm²) respectively in the region in between 10 cm and 30 cm.

Fig. 7. The MC calculated beam profile penumbra for the FFF beam was slightly less (5 cm) than the conventional beam penumura. This is mainly due to the flattening filter removal which reduces the scattered radations.

Fig. 9. The ratios of integrated photon fluence of unflattened / flattened beam were found to be 5.21 and 4.74 for F5 (10 x 10 cm²) and F3 (20 x 20 cm²), respectively.

The results showed that the photon fluence ratio variations for the unflattened beam is dependent on the field size variations.

Fig. 19. The 10% isodose lines for the flattened and unflattened 18 MV photon beam.

• particles number at 0.0 cm was close to zero. Particle distributions peaks found in between 4° to 7° for 20 x 20 cm² and in between 2° to 4° for 10 x 10 cm².

• The calculated distributions peak for both the field sizes for the unflattened beams were less than flattened beam distributions peak.

• The figure illustrates that most of the unflattened photons were produced within the selected with a very few out-field scattered photons, in contrast a large number of flattened photons were scattered out the actual defined field size.

Fig. 18. Shows the patterns plotted for the photons arrival position in 40 x 40 cm² square area at 100 cm from the linac target (SSD) for flattened and unflattened photon beam.