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

M.A. Halato[1], G. Giannini[2], F. Longo[2], A.M. Artoli[1], M.A. Al-Rajhi[3], and I.I. Suliman[3,4,*]

[1]Medical Physics, Faculty of Science and Technology, Al Neelain University, P.O. Box 12702 Khartoum, Sudan.
[2]University of Trieste, Via Valerio, 2 - 34127 Trieste, Italy
[3]Department of Physics, College of Science, Al-Imam Mohammad Ibn Saud Islamic University, Riyadh, Saudi Arabia
[4]Institute of Radiation and Nuclear Safety, Sudan Atomic Energy Commission, P.O. Box 3001, Khartoum, Sudan

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, photon spectra distributions, photon angular distributions, photon x-y position and planner energy fluence)

Materials and Methods

Facilities and Monte Carlo codes

- Beamnrc/dosxyznrc MC codes were used to study the photon beam characteristic in this work because they are giving the most accurate s 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 MeV linear accelerator at Trieste Hospital, Italy

BEAMnrc 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 5x10^9 primary electrons which interact with the accelerator target and produces photon beam.
- The collimator was adjusted to produce an output photon beam of 10×10 cm^2 at 100 cm SSD.
- The emitted photons were scored in wider phase space file of 40×40 cm^2 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 dosxyznrc

The dosxyznrc MC code was used for calculation of the dose distributions in **in 3-D water** r phantom **(Fig. 1)**. These included calculations of percentage depth doses (PDDs) and cross beam profiles.

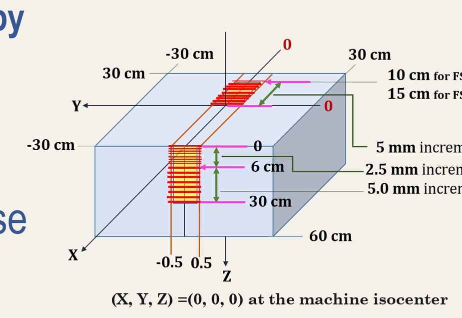


Fig. 1

Experimental measurements

- Percentage depth doses and dose profiles were measured for the 18 MV conventional photon beam for two field sizes $10 \times 10cm^2$ and $20 \times 20cm^2$ at the machine isocenter (100 cm SSD) and were made with 0° accelerator gantry angle (beam pointing down).
- electrometer.

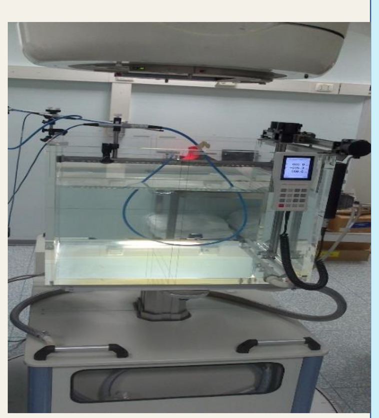


Fig. 2

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

Text Sizes

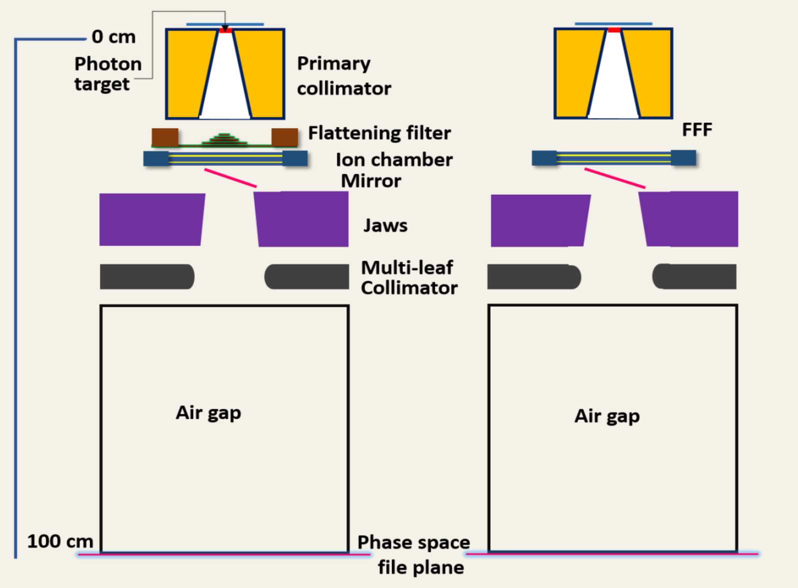


Fig. 3. the Varian Clinac linear accelerator treatment head. The right hand side of the figure shows the FFF linac parts.

Results

Comparison of measured and calculated data

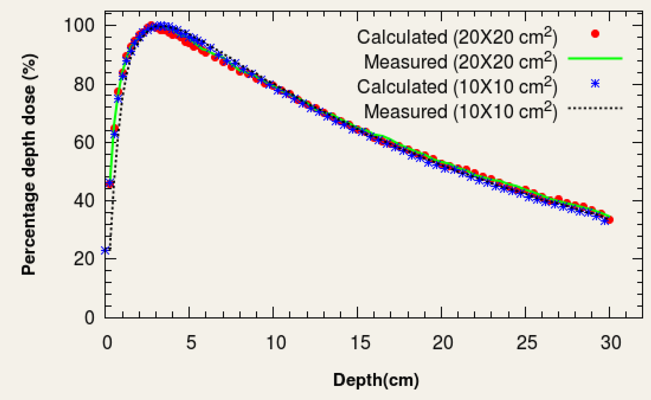


Fig. 4. A comparison of dosxyznrc MC calculated percentage depth dose (PDD) versus water phantom measurements for 18-MV photon beam .

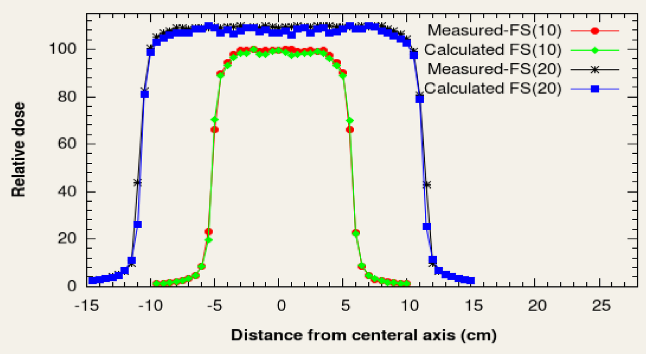
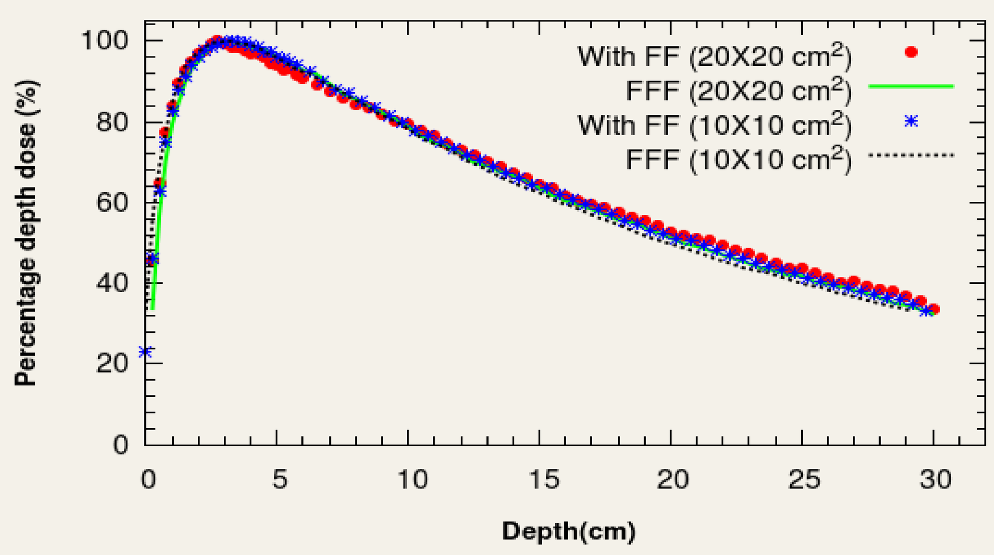


Fig. 5. A comparison of MC calculated beam profiles versus water phantom measurements for 18-MV photon beam at 10-cm depth. The 20X20 field size curves were scaled by a factor of 1.1 to show the plateau region of all the curves in this figure.

- 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 $10 \times 10\ cm^2$, and $20 \times 20\ cm^2$ 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 averaging distance between the calculated and measured doses in the penumbra region for all curves was also within the radiotherapy acceptance criteria of $2\ mm$.

Flattened and unflattened photon beam comparison



- **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 $FS10 \times 10\ cm^2$) and $FS(20 \times 20\ cm^2)$ respectively in the region in between 0.5 cm and 3.0 cm .
- After d_{max} unflattened PDDs became higher than the flattened PDDs and again decreased starting from about 10 cm as clearly shown in Figure 5.3-B an average percentage difference of 1.438% and 3.346% for $FS10 \times 10\ cm^2$) and $FS(20 \times 20\ cm^2)$ 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 mm) than the conventional beam penumbra.
- This is mainly due to the flattening filter removal which reduces the scattered radiations

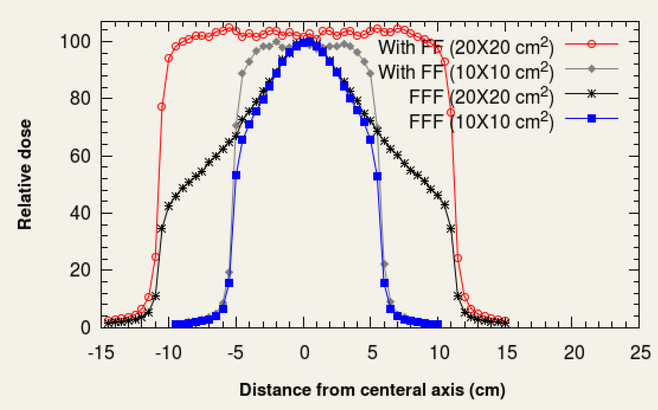


Fig. 7

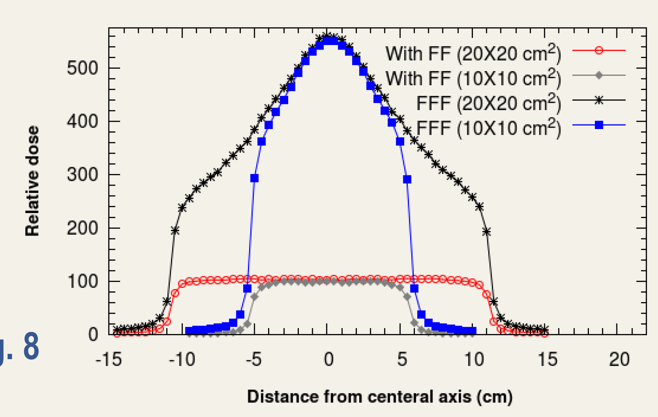
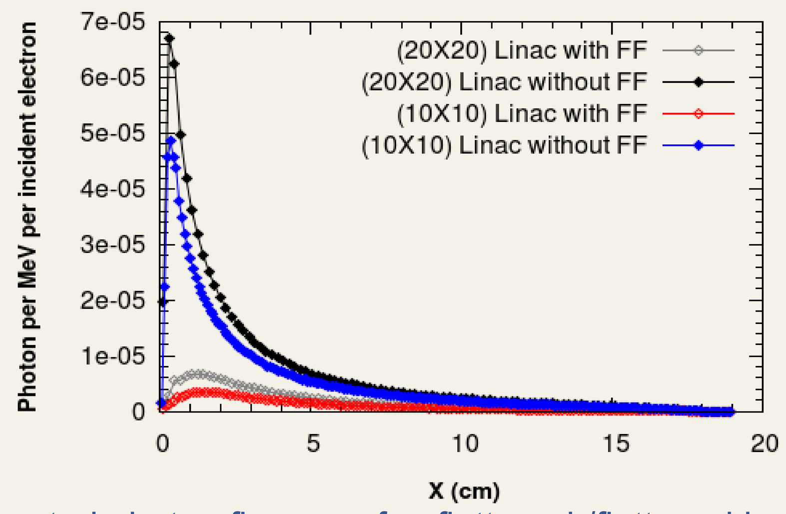


Fig. 8

- 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 $10 \times 10\ cm^2$ and $20 \times 20\ cm^2$, respectively.

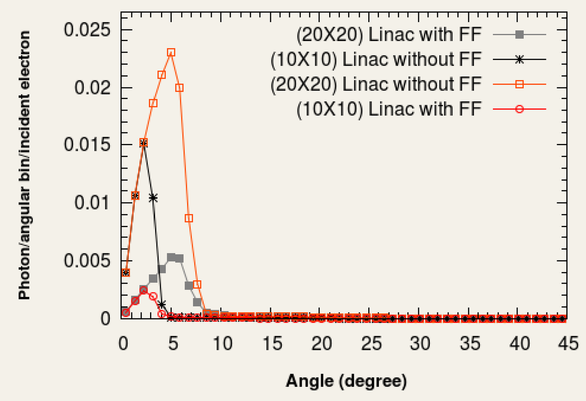
Results

Fig.9 photon energy spectra on the surface of water phantom at the SSD of 100 cm .



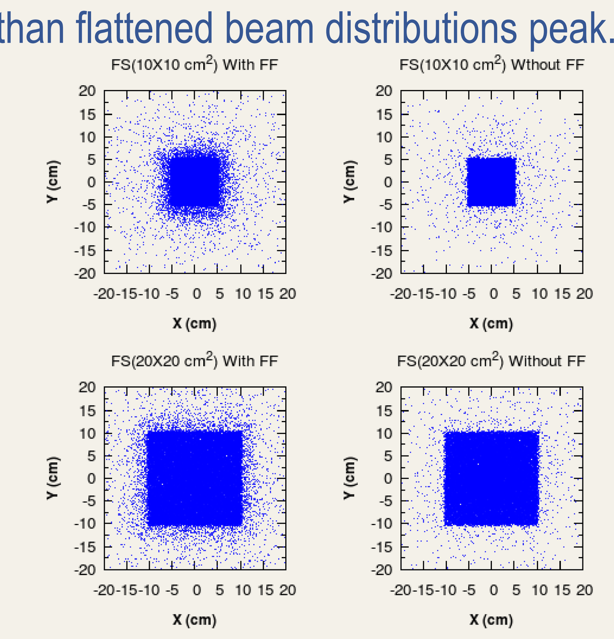
- The ratios of integrated photon fluence of unflattened /flattened beam were found to be 5.21 and 4.74 for $FS(10 \times 10\ cm^2)$ and $FS(20 \times 20\ cm^2)$, respectively.
- The results showed that the photon fluence ratio variations for the unflattened beam is dependent on the field size variations.

Fig. 10 Angular distribution of the flattened and unflattened 18 MV photon beam



- particles number at 0.0^o was close to zero. Particle distributions peaks found in between 4^o to 7^o for $20 \times 20\ cm^2$ and in between 2^o to 4^o for $10 \times 10\ cm^2$.
- The calculated distributions peak for both the field sizes for the unflattened beams were less than flattened beam distributions peak.

Fig. 10 Shows the patterns plotted for the photons arrival position in $40 \times 40\ cm^2$ square area at 100 cm from the linac target (SSD) for flattened and unflattened photon beam.



- 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.

Conclusion

- Initially a Varian Clinac accelerator was modeled by beamnrc MC code and then validated by matching the dosxyznrc calculated beam data with corresponding in phantom measurements.
- This followed by a series of MC simulations for investigating photon beam characteristics and for photoneutrons productions.
- Flattened and unflattened photon spectra have been simulated using beamnrc 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 gives 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 photonuclear reaction.

Acknowledgements

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The corresponding author contact

Ibrahim I. Suliman , PhD
Institute of Radiation and Nuclear Safety, Sudan Atomic Energy Commission,
P.O. Box 3001, Khartoum, Sudan
i.i.suliman@gmail.com