GANTRY ORIENTATION EFFECT ON THE NEUTRON AND CAPTURE GAMMA RAY DOSE EQUIVALENT AT THE MAZE ENTRANCE DOOR IN RADIATION THERAPY

by

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In the present study, the effect of gantry orientation on the photoneutron and capture gamma dose calculations for maze entrance door was evaluated. A typical radiation therapy room made of ordinary concrete was simulated using MCNPX Monte Carlo code. Gantry rotation was simulated at eight different angles around the isocenter. Both neutron and capture gamma dose vary considerably with gantry angle. The ratios of the maximum to the minimum values for neutron and capture gamma dose equivalents were 1.9 and 1.4, respectively. On the other hand, comparison of the Monte Carlo calculated mean value over all orientations with Monte Carlo calculated neutron and gamma dose showed that the Wu-McGinley method differed by 5% and 2%, respectively. However, for more conservative shielding calculations, factors of 1.6 and 1.3 should be applied to the calculated neutron and capture gamma doses at downward irradiation. Finally, it can be concluded that the gantry angle influences neutron and capture gamma dose at the maze entrance door and it should be taken into account in shielding considerations.

Key words: Monte Carlo method, gantry, dose equivalent, photoneutron

INTRODUCTION

Radiation therapy using high-energy photon beams proved to have a significant effect on the quality of cancer treatments. To deliver the prescribed dose to the target volume and avoid normal tissue irradiation, the beams are usually delivered from several angles while the gantry rotates around the treatment table. In treatments with high-energy X-ray beams (E >10 MeV) photoneutrons are produced through (γ, n) interactions in linac head components [1-11].

There are several methods to estimate the fluence and dose equivalent of these neutrons in the radiation therapy room [4, 5]. The proposed analytical methods for photoneutron calculations at the maze entrance door, do not consider the orientation of the photon beam but, a more applied, downward directed beam. As the neutron dose in the maze varies with gantry orientation [3], the neutron calculations using only downward direction may result in either overestimation or underestimation of the maze entrance door shielding calculations.

Previous measurements have shown that the neutron dose in the maze reaches its maximum when the head of linac is located at the closest distance to the inner maze entrance [3]. The neutron dose in the maze is the lowest when the gantry head is farthest away. A difference of a factor of 2 could be seen between the two gantry angles. Moreover [3], according to Wu-McGinley in the downward direction of the beam the dose is slightly higher than the average of the two extreme cases. In a recent study the neutron dose at several points inside a radiotherapy room was evaluated by Monte Carlo (MC) method [7]. However, the accuracy of the recommended analytical method concerning the gantry orientation needs to be evaluated. To address this issue, in the present study, the effect of gantry orientation on the neutron dose at the maze entrance door was studied by the MC method. In addition, the photo neutron and neutron capture gamma ray dose equivalents were calculated with the recommended analytical methods. Both analytical and MC methods were used to calculate the mean, maximum, and minimum values of neutron and gamma ray doses in all orientations, and the results were compared.

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MATERIALS AND METHODS

Analytical method for neutron calculation

The International Atomic Energy Agency (IAEA) in its Report No. 47 recommended an analytical method for calculation of neutrons fluence in the treatment room. This method was also recommended by the National Council on Radiation Protection and Measurements (NCRP), Report No. 151, and is given by eq. (1) [12]

$$\varphi_{\mathrm{A}} \quad \frac{Q_{\mathrm{N}}}{4\pi d^2} \quad \frac{5.4Q_{\mathrm{N}}}{2\pi S} \quad \frac{1.26Q_{\mathrm{N}}}{2\pi S} \tag{1}$$

where Q_{N} [nGy^{-1}]is the linac neutron source strength and gives a number of totally produced neutrons when isocenter absorbs 100 cGy dose, d [m] – the distance of point A to the isocenter, S [m^2] – the total inner surface area of the room, and φ_{A} [nm^{-2}] – the neutron fluence at any point A. Figure 1 shows the parameters used in analytical method for neutron fluence calculation.

Wu-McGinley method [3] for a single-bend maze which expresses exponential attenuation of photoneutrons is as follows

$$D_{\mathrm{n}} \quad 2.4 \;\; 10^{\;15} \varphi_{\mathrm{A}} \sqrt{\frac{A_{\mathrm{r}}}{S_1}} \quad 1.64 \;\; 10^{\frac{d_2}{1.9}} \quad 10^{\frac{d_2}{T_N}} \tag{2}$$

where D_{n} [Sv/Gy] – the photoneutron dose equivalent at the maze entrance door, φ_{A} [nm^{-2}] – the total neutron fluence at point A per X-ray [Gy], A_{r} [m^2] – the cross-sectional area of the inner maze entrance, S_1 [m^2] – the cross-sectional area of the maze door, d_2 [m] – the distance from the point of measurement to the point A, and T_{N} [m] – the tenth value length, fig. 1.

For neutron capture gamma ray dose equivalent eq. 3 was proposed by Wu-McGinley [3]

$$D_{\varphi} \quad 5.7 \;\; 10^{\;16} \varphi_{\mathrm{A}} \;\; 10^{\frac{d_2}{6.2}} \tag{3}$$

In this equation, D_{φ} [Sv per Gy of X-ray at the isocenter] is the neutron capture gamma ray dose equivalent at distance of d_2 [m] from point A at the inner maze entrance.

Monte Carlo simulations

The MCNPX (2.4.0) code was used for simulations in the present study [8]. The LA150U photonuclear library of MCNPX was used in the entire simulations. Main parts of Varian 2100 Clinac for 18 MeV photon beam were simulated. Initial electron beam, target, container, primary and secondary collimators, movable jaws, flattening filter, and linac head shielding were the simulated parts for calculations. The model was validated and used in a previous study [2, 9]. A 50 × 50 × 50 cm^3 water phantom with a source to surface distance of 100 cm inside a typical 12.7 × 11.5 × 4.2 m^3 radiation therapy room made of ordinary concrete were simulated. The composition of concrete was in compliance with the NCRP No. 144 recommendation concerning shielding material . The simulated room geometry is shown in fig. 1.

The gantry rotation was simulated in clockwise direction/rotation with a 45-degree interval. Simulated orientations of gantry are shown in fig. 2. A cylindrical water cell with a radius of 1 cm and a height of 0.2 cm was positioned at d_{max}, to score photon-absorbed dose in each orientation. In addition, a spherical water cell was positioned at the maze entrance door to score the neutron and capture gamma ray dose. The F6 tally was used to score deposited energy in the scoring cell in terms of MeV per gram of a cell material per initial electron. Photon dose and neutron dose were scored for each orientation per initial electron separately. Applying also the F6 tally, the neutron capture gamma ray

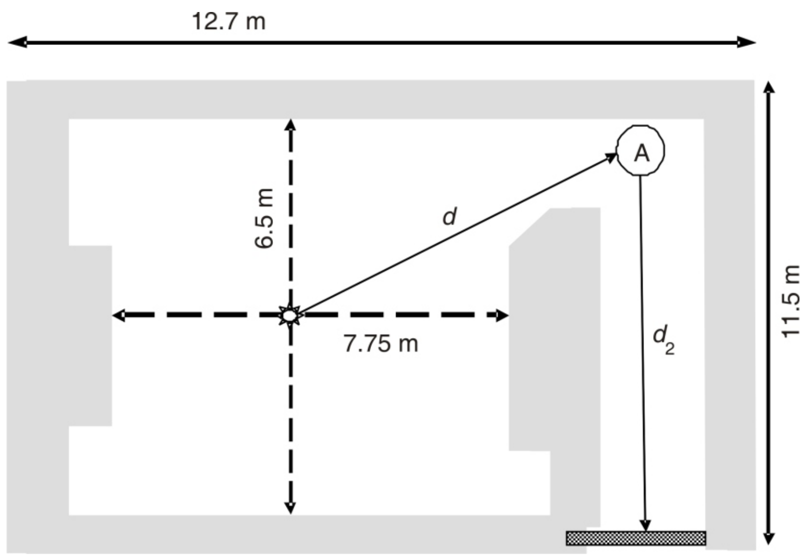

Figure 1. Simulated room layout and dimensions used for calculations

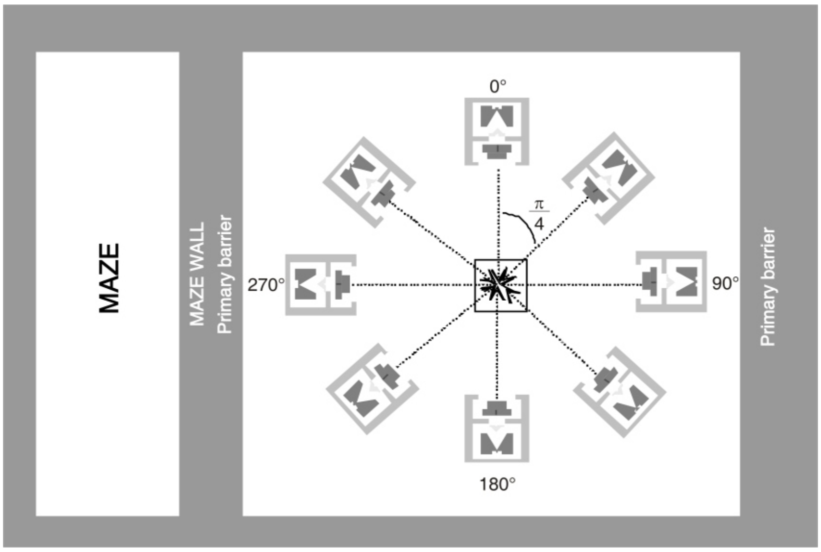

Figure 2. The side view of room in different orientations of gantry

dose was obtained. In addition, the forth entry of photon PHYS: CARD was set to 1 to enable the biased photonuclear production for speeding up the simulations. Neutron and capture gamma doses were normalized to photon dose at $d_{\max}$ in the same orientation to obtain the value in terms of Gy of neutron or gamma per Gy of photon dose of isocenter. Applying the most conservative radiation weighting factor of 20 based on the ICRP Report No. 103 for neutrons [10], dose values were converted to Sv/Gy of isocenter.

Neutron source strength of the simulated linac was set to $1.3 \cdot 10^{12}$ neutrons per Gy of isocenter according to the previous modeling [2]. Multiplying this value by neutron dose equivalent per initial electron, results in the neutron dose equivalent in mSv per Gy X-ray at the isocenter. Similarly, neutron capture gamma ray dose was obtained by applying the same neutron source strength.

RESULTS AND DISCUSSION

Neutron and capture gamma dose was obtained by MC calculation for different gantry orientations (tab. 1). It is seen that neutron and capture gamma dose equivalents change significantly with gantry angle. The lowest values of neutron and capture gamma dose were attained at 90 deg., with the linac head far from the maze entrance door while the highest values were reached at 270 deg., when the distance between the linac head and the maze entrance door was the shortest.

Neutron dose equivalent was also calculated using the Wu-McGinley method and the results compared with the MC mean value. The neutron dose equivalent determined by the Wu-McGinley method was $2.7 \cdot 10^{-3}$ mSv/Gy, while the mean MC value calculated over all angles was $2.5 \cdot 10^{-3}$ mSv/Gy, showing a 5% difference.

Table 1. Neutron and capture gamma dose equivalent [mSv/Gy] for different gantry orientations at the maze entrance

Angle of rotation (deg.)	Neutron dose equivalent	Capture gamma dose
0	$(2.3\quad 0.02)\cdot 10^{-}$	$(2.1\quad 0.02)\cdot 10^{-}$
45	$(2.2\quad 0.02)\cdot 10^{-}$	$(2.1\quad 0.02)\cdot 10^{-}$
90	$(2.0\quad 0.02)\cdot 10^{-}$	$(1.9\quad 0.01)\cdot 10^{-}$
135	$(2.4\quad 0.02)\cdot 10^{-}$	$(2.0\quad 0.01)\cdot 10^{-4}$
180	$(2.9\quad 0.02)\cdot 10^{-}$	$(2.3\quad 0.02)\cdot 10^{-4}$
225	$(2.4\quad 0.02)\cdot 10^{-}$	$(2.5\quad 0.02)\cdot 10^{-}$
270	$(3.7\quad 0.03)\cdot 10^{-}$	$(2.8\quad 0.02)\cdot 10^{-4}$
315	$(2.6\quad 0.02)\cdot 10^{-}$	$(2.2\quad 0.01)\cdot 10^{-4}$

Capture gamma dose was also determined by the Wu-McGinley method and the results compared with those obtained by MC method, as in the case of neutrons. While the Wu-McGinley capture gamma dose equivalent was $2.2 \cdot 10^{-3}$ mSv/Gy, the MC method showed $2.1 \cdot 10^{-3}$ mSv/Gy average over all gantry angles. The results were very close together (2% difference) which showed that the studied analytical method primarily leads to reliable results for capture gamma dose calculation for shielding purposes concerning different gantry orientations. On the other hand, minimum and maximum values for neutrons were $2 \cdot 10^{-3}$ and $3.7 \cdot 10^{-3}$ mSv/Gy. In other words, it showed that when gantry was closer to maze-wall, there were 1.9 times more neutrons than when it was far from maze wall. Additionally, for capture gamma this value was 1.4. Our MC results were in good agreement with measurements of Wu-McGinley [3]. In the study of Wu-McGinley, the ratio of the maximum to the minimum neutron equivalent dose for different gantry orientation ranged from 1.7 to 2.4 at three measurement points in the maze. In the study of Rebello *et al.* on the neutron dose, a ratio of the maximum to the minimum of 1.59 was found between the gantry angles of 225 and 90 deg. at the maze entrance door. Our results were higher than their results which can be attributed to differences in room geometry and MC simulations [7]. It is worth mentioning that we have not found any study on capture gamma dose variation with different gantry angles.

Different studies on the photoneutron calculations for the maze entrance door have considered only one orientation in neutron and capture gamma dose calculation in the radiation therapy room. On the other hand, the available analytical methods do not take into account gantry orientation in their calculations. However, in practice, several gantry angles are used for patient treatments. Thus, the dose received by the maze entrance door would be the average of neutrons and capture gamma rays produced in different gantry angles. In the current study using the mean neutron and gamma dose obtained by MC method, it was found that analytical methods can estimate the neutron and capture gamma dose in close agreement with MC method. However, if the maximum values of both neutron and capture gamma doses at 270 deg. are considered for most conservative shielding calculations, the application of the Wu-McGinley method will result in considerable underestimation of a thickness of the maze door. Therefore, taking into account the gantry angulation in shielding calculations, it is recommended to apply factors 1.6 and 1.3 to the neutron and gamma calculations at the zero angle irradiation.

Our finding is in a close agreement with results of Martinez *et al*., who evaluated the neutron dose around two linacs for different gantry orientations [11]. Although the neutron dose at the maze entrance was not calculated in their study, their results confirmed the point that the neutron dose is significantly dependant on the gantry orientation [11].

CONCLUSIONS

The effect of different gantry angles on photoneutron and capture gamma dose at the maze entrance door was studied by MC method. Our MC results showed a considerable variation in neutron and capture gamma dose with gantry orientation. The results of analytical methods which do not consider gantry orientation were compared with the MC results. The Wu-McGinley method showed reliable results in comparison to the MC results. It is recommended that radiation protection experts be cautious in applying the analytical methods for neutron and capture gamma dose calculations. In addition, in order to provide a more accurate shielding estimation, the effect of gantry angles should be taken into account for neutron and capture gamma dose calculation at the maze entrance door.

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УТИЦАЈ ПОЛОЖАЈА ПОРТАЛНОГ КРАНА НА ЕКВИВАЛЕНТНУ ДОЗУ ФОТОНЕУТРОНА И ГАМА ФОТОНА У УЛАЗНИМ ВРАТИМА ЛАВИРИНТА СОБЕ ЗА РАДИОТЕРАПИЈУ

У раду је процењен утицај оријентације порталног крана на прорачун дозе од фотонеутрона и гама фотона у вратима лавиринтског ходника. Типична соба за радио терапију, саграђена од обичног бетона, симулирана је помоћу MCNPX Монте Карло кода, а ротација порталног крана моделована је у осам различитих углова око изоцентра. Дозе од неутрона и гама фотона значајно варирају у зависности од угла порталног крана. Односи максималне и минималне вредности дозног еквивалента су 1,9 за неутроне и 1,4 за гама фотоне. Поређење средњих вредности доза за неутроне и гама фотоне, рачунате Монте Карло кодом и Ву-Мекгинлијевом методом по свим оријентацијама, показује да резултати међусобно одступају за 5% и 2%, респективно. Може се закључити да оријентација порталног крана утиче на дозе неутрона и гама фотона на улазним вратима у лавиринтни ходник и да је треба уврстити у разматрање при пројектовању заштитних баријера.

Кључне речи: Монте Карло метода, портални кран, еквивалентна доза, фотонеутрони