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Original Research

Measurements of photoneutron dose rate for 15 MV photon beam from medical linear accelerator using neutron survey meter

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Abstract: High-energy medical linear accelerators (>10MV) are increasingly used in the medical field to treat cancer patients depending on the treatment organ and patient physic. Medical linear accelerators (Linacs) operating above 10 MV photon beam produce unwanted neutrons (photoneutron) by means of photonuclear reaction (γ, n) between bremsstrahlung photon beams and constituent materials of Linac head. This study involved the measurement of the neutron dose rate from photon beam of medical linear accelerator (Elekta Synergy) operated at 15 MV photon. For the measurement of dose rate, a neutron survey meter LB 6411 probe was used. Neutron dose rate was obtained as a function of delivered dose, field size and detector position. In the study neutron dose rate was found 13.14 mSv/h at a field size of 10 × 10 cm^2 at position (0, 90, 0) cm for 350 cGy and 9.26 mSv/h at 5 × 5 cm^2 field size at position (0, 80, 0) cm for 200 cGy photon dose delivery. The dose rate varied with respect to detector position in an irregular manner; 2.95 mSv/h at position (-100, 0, 0) cm -on the side of maze entrance and 4.85 mSv/h at position (100, 0, 0) cm -off side of maze entrance.

Keywords: Cancer, Radiotherapy, Medical Linac, Bremsstrahlung, Survey meter, Photoneutron, Neutron Dose Rate

Introduction

Cancer is the leading cause of death across the globe [1]. Treatment of cancer includes different modalities such as surgery, chemotherapy, radiation therapy and hormone therapy [1-3]. Among these modalities radiotherapy is used to treat cancer in more than 50% of cases and approximately 40% of patients survive by taking radiotherapy treatment [4,5]. External beam radiotherapy (EBRT) (photons/electrons/protons), implanted radioisotopes (brachytherapy) and injected radioisotopes are the main methods to deliver radiation therapy. EBRT with photons and electrons is the most common type of radiotherapy. Most types of external beam radiation therapy use a linear accelerator (Linac) machine to speed up the particles and deliver them to cancer cells [3,4]. In Linac, high energetic accelerated electrons are directed towards high Z target and converted to bremsstrahlung photons which are used in cancer treatment [6]. During high energy photon beam therapy, bremsstrahlung photons above the threshold of (γ, n) of high Z materials produce unwanted neutrons interacting with the constituent

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elements in the Linac head (such as: target, field-flattening filters and beam collimators) [7]. Interaction of high energy photon with patients and treatment room wall could be another source of photoneutrons in radiation therapy [8]. The lighter elements of Linac head also take part in photonuclear reaction but threshold energy for (γ, n) reaction of lighter elements is higher than high Z materials because threshold energy for a photonuclear reaction is dependent on the atomic number of material and it decreases with the increasing value of Z [9,10]. Moreover, peak (γ, n) cross sections for high Z materials are around 50 times higher than that for low Z ones. Thus, photonuclear reactions through the interaction of high energy X-ray photons with high Z constituent materials of Linac head and collimation system, are the main source of photoneutron production in radiotherapy [9]. Photoneutrons have great probability to penetrate the shielding and reach the patient and bunker walls as the main neutron producing material such as tungsten has very low absorption cross section for the energy range of neutron produced in Linac head [8]. From various studies, it is known that the photoneutron energy spectrum peaks are between 100 keV and 1 MeV [8,10]. These neutrons are very effective in cell damaging due to their significant radiation weighting factor (W_R = 20) and that is why the unwanted photoneutron is a protection issue [11]. Advancing radiation treatment technology produces a precise shaping of dose distributions to target tissues sparing the normal tissues which results in higher contribution of photon and neutron peripheral doses when the energies are above 10 MV [12]. So, the concern of second cancer and other health risks arising from the neutron contamination is necessary but least taken into account. This study focuses on the measurement of neutron contamination in photon and neutron mixed field inside the treatment room by using survey meter. If the treatment room is arranged in such way only to shield photon, the neutron produced from Linac head will diverge around. Besides, if the maze is not constructed suitably, the consequence can be also critical for worker health. The neutron contamination should be taken into consideration for patient health and this issue is equally important for the optimization of the dose to workers. A.P. Salgado *et al*. measured neutron dose rate at the Instituto Nacional do Cancer (INCa) in the linear accelerator Varian Clinac 2300 C/D operated at 15 MV and the gantry was set at 0° for field size 10 × 10 cm^2. The measurements were taken for three positions; which are 100 cm from isocenter, at the entrance of the maze, just inside and outside the door. From this study it is obvious that the dose rate is lower inside the maze entrance and inside and outside of the door than at 100 cm from isocenter [13]. Duong *et al*. investigated neutron dose rate for different field sizes at various locations within and outside of a 15 MV Siemens Primus M5497 electron accelerator treatment vault using a neutron survey meter. This study showed that low values ranging from unobservable to between 0.0001 to 0.0002 mSv/h neutron dose rate around the control room and patient waiting area where the greatest value at the level of the floor directly adjacent to the treatment couch is 8.6 mSv/h which exceeds the greatest value on the treatment table 5.5 mSv/h [14]. In the present study, we have measured neutron dose rate for 15 MV photon beam at various locations inside the Linac treatment room as a function of delivered photon dose, field size(s) and at various location inside the treatment room.

Materials & methods

The Linac used under this investigation is Elekta Synergy located in Enam Medical College & Hospital, Savar, Dhaka, Bangladesh. Different parts of an Elekta Synergy are, X-ray target made of tungsten and rhenium disk, primary conical collimator - made of tungsten alloy, X-ray beam flattening filter - made of stainless steel, transmission chambers - made of aluminum alloy or ceramic, multi-leaf collimator - made of tungsten, and asymmetric jaws - made of tungsten [15,16]. A neutron dose rate monitor LB 6411 was used for the measurement of neutron dose rate at the Linac treatment room. The LB 6411 consists of a 3He proportional counter tube surrounded by a polyethylene moderator sphere. This probe is sensitive to thermal neutron. To enable the detector to detect neutrons of higher energies, the neutrons are thermalized by the moderator. The neutron measuring range of LB 6411 probe is from 100 nSv/h to 100 mSv/h and neutron energy response range from thermal to 20 MeV. The detector is calibrated at Berthold Technologies GmbH & Co. which is traceable to the Physikalisch-Technische Bundesanstalt (PTB), Germany. The calibration factor of the instrument is 1.27 μSv/h/cps for Am-Be neutron radiation source with relative deviation is 6.6% for ambient dose equivalent according to ICRP 74. The technical data of LB 6411 was collected from the Secondary Standard Dosimetry Laboratories (SSDLs), Savar, Dhaka, Bangladesh. An Alderson Rando male Phantom was placed on the treatment couch for irradiation. The survey data of Linac treatment were taken as a function of delivered dose, field size and detector position. For the whole experiment, SSD was kept at 100 cm. To obtain the live time data, the survey meter was observed by camera view from the control room. The positions of detector were taken with respect to the isocenter (0,0,0). The assumed Linac axis is shown in Figure 1(a) and Figure 1(b) and the design of Linac room of Enam Medical College & Hospital, Dhaka, Bangladesh is shown in Figure 2.

Results & discussion

Neutron dose rate as a function of delivered dose

The survey meter was exposed under 10 × 10 cm^2 field size, at position (0, 90, 0) cm for delivered dose 100, 150, 200, 250, 300 & 350 cGy. The field size & the position

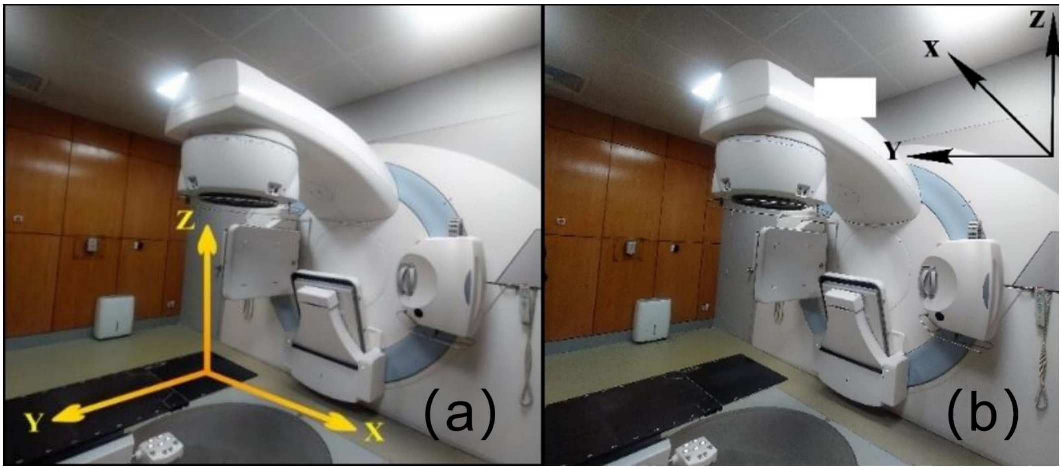

Figure 1. Assumed axis of Linac Elekta Synergy (a) & (b) located in Enam Medical College & Hospital, Savar, Dhaka, Bangladesh

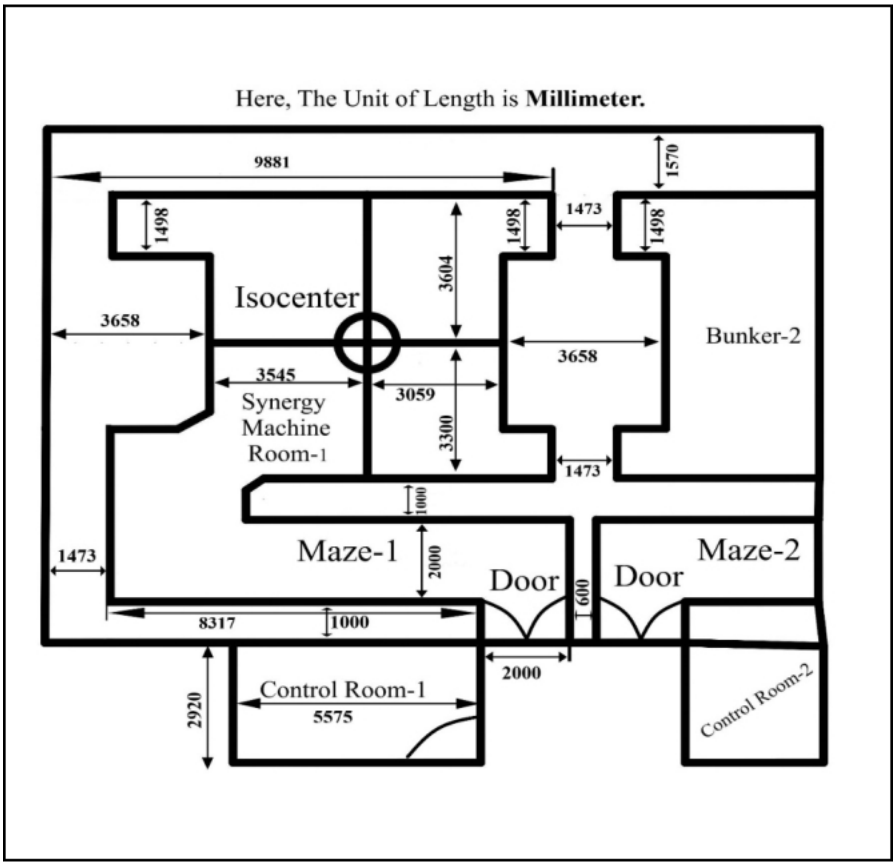

Figure 2. The design of Linac room of Enam Medical College & Hospital, Savar, Dhaka, Bangladesh

were kept fixed to obtain the results as a function of delivered dose. Table 1 and Figure 3 show the data and linear response of survey meter as a function of delivered dose. The response indicates that the dose rate increased linearly with the increase of delivered dose. A study conducted by A.P. Salgado *et al*. also showed that the dose rate increases with increase of the delivered dose [13].

Neutron dose rate as a function of field size(s)

Table 2 and Figure 4 show the variations of dose rate as a function of field size(s). It is expected that the more congested the head materials are, the more photoneutrons are observed because probability of photonuclear reaction is higher as the photon beams traverse more materials. During the smallest field size, the jaws and MLCs of the Linac head remain close to each other and neutrons are produced via photonuclear reaction between the photon and the materials. Theoretically more photoneutron dose rate should have been observed for low field size, but lowest dose rates were observed for 1 × 1 cm^2 because the generated photoneutrons are absorbed by the shielding created due to low field size inside the Linac head. Though jaws and MLCs remain closer for the case of 1 × 1 cm^2 than 5 × 5 cm^2, neutron dose rate found for the field size 5 × 5 cm^2 is greater than for field size 1 × 1 cm^2. It happened because most photoneutrons are produced from the upper components of the Linac head, such as the primary collimators, the target and the flattening filter, not the jaws. The photoneutron generated from the upper level can pass more through the wider path of field size 5 × 5 cm^2 than field size 1 × 1 cm^2.When the field size is very small, the jaws provide a shielding to the upstream photoneutrons. After reaching at field size 5 × 5 cm^2, with increase of field size the dose rate starts to drop which is in good agreement with a study conducted by Wang *et al*. [17]. Because after reaching a certain field size, with increase of field size the probability of photonuclear reaction reduced.

Table 1. Neutron dose rate as a function of delivered dose

Field Size (cm^2)	Position (cm)	Patient Dose (cGy)	Neutron Dose Rate (mSv/h)
10 × 10	(0, 90, 0)	100	3.04 ± 0.69
		150	7.29 ± 0.8
		200	9.18 ± 0.49
		250	10.73 ± 0.08
		300	12.22 ± 0.06
		350	13.05 ± 0.09

Table 2. Neutron dose rate as a function of field size(s)

Detector Position (cm)	Patient Dose (cGy)	Field size (cm^2)	Neutron Dose Rate (mSv/h)
(0, 80, 0)	200	1 × 1	3.44
		5 × 5	9.26
		10 × 10	8.44
		15 × 15	7.79
		20 × 20	8.08
		25 × 25	7.58

Neutron dose rate as a function of detector position

The linac was operated for a dose of 100 cGy keeping the field size fixed for various positions of the detector. The positions were taken with respect to the position (0, 0, 0). Table 3, Table 4, Figure 5 and Figure 6 show the variations of dose rate as a function of the detector position. From the Figure 5, we can notice that, variations of dose rate did not follow a sharp way. From the transport theory approach, at a given location the neutrons are sorted according to their direction and each bundle of neutrons having a specific direction [18]. Initially collimated neutrons travel toward the target and get scattered in various directions. Very near of the target area the created solid angle may exclude the detector region. This is the reason that dose rate increases with the increase of distance of detector. After a certain position the effect of solid angle gets mitigated due to the diffuse nature of neutron and the value of dose rate starts to drop linearly with increasing distance of detector position.

Again, the detector was placed at the two opposite sides of the isocenter having same field size 10 × 10 cm^2. The dose rate at position G (100, 0, 0) which is the opposite side of maze entrance is decreased by 39.2% when the detector position is at F (-100, 0, 0) which is on the side of maze entrance (shown in Table 4 and Figure 6)This may happen for two reasons; the point G is closer to primary shielding wall than the point F and that is why the number of scattered neutrons produced in the wall was more in position G. And another reason is, the point F is closer to the maze entrance than the point G which means the probability of neutron scattering is low at point F as the neutrons can easily travel towards the maze and absorbed by the door. This result is in good agreement with a study conducted by Wang *et al*. [17], where they showed the variations of Neutron Equivalent Dose (NED) at various positions of the treatment room.

Conclusion

The study was concerned about measuring neutron dose rate of medical Elekta Linac operating at 15 MV potential. The results found in this study depend on delivered dose, field size and detector position. In case of position dependency, the dose rate varied in an irregular manner which can be concluded that dose rate is higher where the detector gets more neutrons from the Linac and neutron scatterer such as patient body & bunker wall. As photoneutrons are observed in this study, the issue of additional protection for photoneutron dose should be taken into account considering the risks for both of the patient and occupational worker safety.

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Author's contribution

M. Ummey Habiba Musfika contributed to the conception and design of work, performed experimental work, data analysis, interpretation of data and writing of article.

Table 3. Neutron dose rate as a function of detector position

Field Size (cm^2)	Patient Dose (cGy)	Detector Position (cm)	Neutron Dose Rate (mSv/h)
		A (0,60,0)	3.03
10 × 10	100	B (0,70,0)	4.35
		C (0,80,0)	5.39
		D (0,90,0)	4.88
		E (0,100,0)	4.29

Table 4. Detector responses at two opposite sides of the isocenter

Field Size (cm^2)	Patient Dose (cGy)	Detector Position (cm)	Neutron Dose Rate (mSv/h)
10 × 10	100	F (-100,0,0) -on the side of maze entrance	2.95
		G (100,0,0) -opposite side of maze entrance	4.85

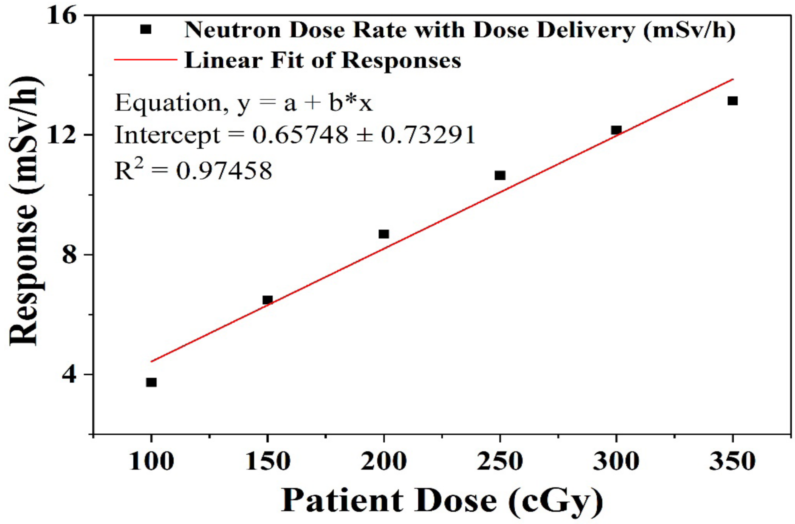

Figure 3. Variations of neutron dose rate as a function of photon dose delivery

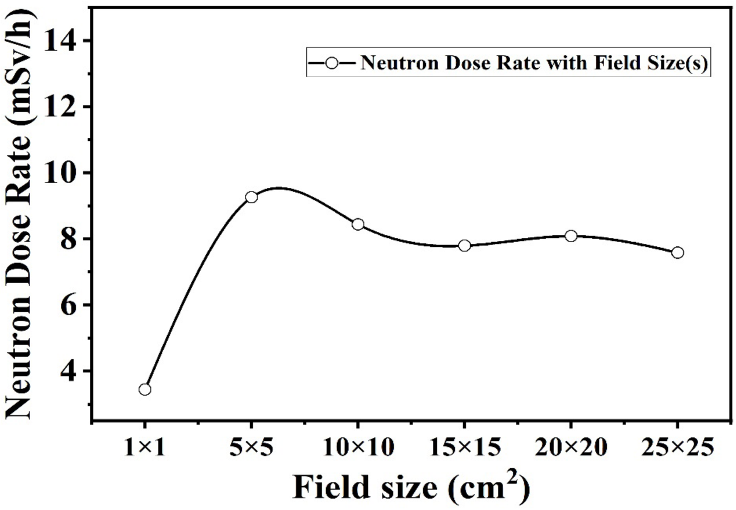

Figure 4. Variations of neutron dose rate as a function of field size(s)

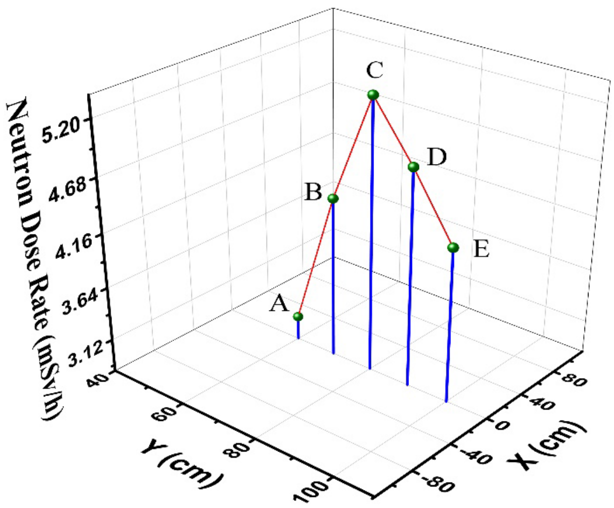

Figure 5. Variations of neutron dose rate as a function of detector position on y-axis

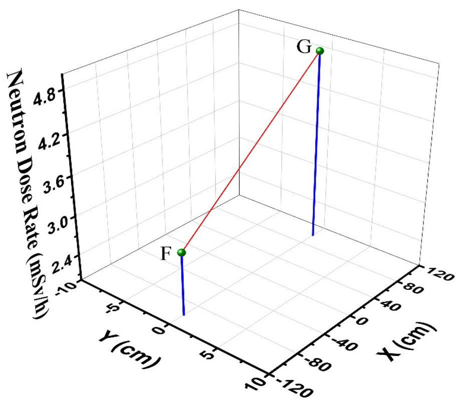

Figure 6. Variations of neutron dose rate as a function of detector position on x-axis

Hossen Mohammad Jamil gave the accelerator exposure planning and experimental design verification. Tanjim Siddiqua investigated the accuracy of work and resolved. Md. Shakilur Rahman gave the concept and design of the work, contributed to literature review and jointly supervised the research. AKM Moinul Haque Meaze supervised the whole study and corrected the article. All authors reviewed and approved the final version of the manuscript.

Conflict of interest

The authors declare that they don't have any conflict of interest.

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Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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