The Measurement of Photoneutron in the Vicinity of Siemens Primus Linear Accelerator

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INTRODUCTION

The latest and most advanced medical linear accelerator, the Siemens Primus, can provide dual photon energies, 6 and 15 MV. It is capable for the Intensity Modulated Radiation Therapy (IMRT) purpose by coupling dynamic wedge and multileaf, and a new one is installed in the Department of Radiation Oncology, Changhua Christiah Hospital. Since the photon energy due to 15 MV acceleration is higher than the threshold energy, 6 MeV, of photoneutron production of main shielding and modulating material, tungsten, then the neutron contamination is of much concern (1). According to NCRP Report 116, the radiation weighting factor W_R for neutron ranging from 5 to 20 MeV are quite large and would expect quite significant dose equivalent to the critical organs, gonads and lens in patients (2).

At the isocenter, the fluence Φ (n cm^{-2} per Gy-x) of photoneutron production per unit x ray dose is as follows (3):

$$\Phi = \Phi_{dir} + \Phi_{sc} + \Phi_{th} = \frac{aQ}{4\pi d^2} + \frac{5.4aQ}{S} + \frac{1.26Q}{S} \qquad [1]$$

where Φdir is the direct neutron fluence, Φsc the scatter neutron fluence, Φth the thermal neutron fluence, Q the neutron source strength per Gy-x of linac, a is the transmission factor for linac head (for Pb a = 1 and W = 0.85), d the distance (cm) between measured point and target, and S the area of treatment room (cm2). The Q value is varied for different linacs including Varian series, Philip series, GE series and part of Siemens series with the exception of Siemens Primus (3). For shielding purpose, it is not suitable to cite other linac data for Siemens Primus. Thus, the objective of this work is to measure the photoneutron relevant data for Siemens Primus in shielding design.

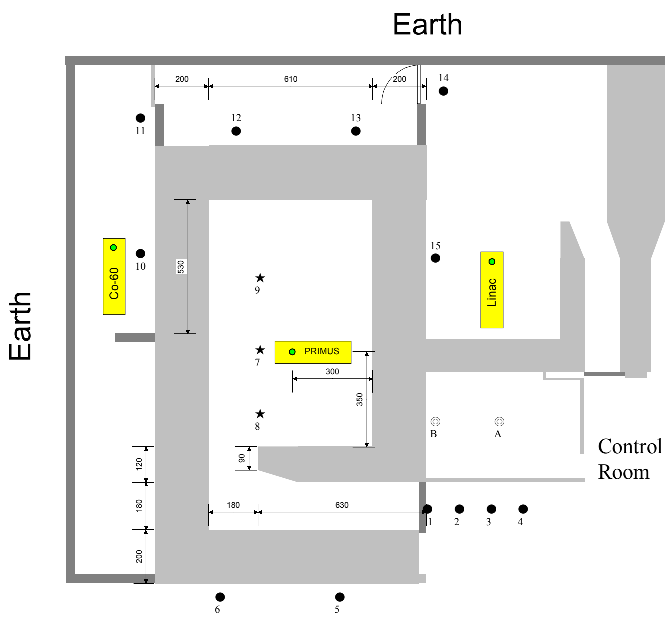

Figure 1. Points of measurement in the vicinity of shielding (●).

MATERIAL AND METHODS

This work includes the four parts of measurements. [1] Portable neutron rem-meter (Harwell Co. N91) calibrated with shadow cone method was used for environmental survey in the vicinity of treatment room with the area of 40 x 40 cm2, and the condition of 500 MU/min with gantry angle 0°, 90°, 180°, and 270° at 100 cm height (4). The measured points were shown as circle spots in Figure 1. [2] Neutron detection module, including BF_3 proportional counter encased by 3" or 9" diameter PE sphere, was used for mean neutron energy distribution measurement in treatment room. The measured points were 1,2,3 and 5 meters away from the isocenter with field size fully opened and dose rate of 500 MU/min. The response ratio of 9"/3" is a function of the Hankins calibration factor, and is related to the mean neutron energy. [3] Neutron activation analysis of Au foil, which covered with 6" PE, was irradiated in the x rays field with dose of 50 Gy, and was used to determine neutron contamination, and [4] powdered P_2O_5 was used to measure the thermal and fast neutron fluence in the x ray field. This method utilizes two reactions: (a) 31P(n, γ)32P, where the half life of 32P is 14.28 d and emits βmax of 1.71 MeV. This reaction is mainly due to thermal neutrons with a cross section of 0.19 barn. (b)^{31}P(n,p)^{32}Si, where the half life of ^{32}Si is 2.62 h and emits βmax 1.48 MeV with the threshold energy of 0.7 MeV. The β can be counted with liquid scintillator and the saturated activity of ^{31}Si and ^{32}P are related to fast and thermal neutron fluence, respectively (5).

RESULTS AND DISCUSSION

Environmental survey with a portal rem-meter at all points with various irradiated conditions are all in background level which is less than 0.04 μ Sv/h demonstrating that shielding design is effective for photoneutrons. The mean energy of photoneutrons measured by paired BF_3 proportional counters at different points is list in Table 1. The A,B,C,D and E are other linacs installed in Taiwan with various energy. It shows that decreasing mean energy is related to increasing distance to isocenter. For Siemens Primus, 1, 2, 3 and 5m away from isocenter are 0.50, 0.20, 0.16 and 0.17 MeV, respectively, which was caused by different levels of moderation that depends on the schematic layout of the treatment room. Mean neutron energy produced by high energy photons was found to be no significant relation to photon energy and types of linacs. The mean neutron energy at maze, 0.02 MeV, is much less than that in treatment room, which was caused by about additional 5 scatters in concrete. The importance of maze is not only to increase the scatters of photon but that of neutron as well, that significantly reduce the neutron shielding material needed in a lead door.

Table 1. Mean neutron energy (MeV) at different points in treatment room of various linacs (4)

Hospital	Distance to isocenter(m)	Ratio of 9"/3" BF_3	Mean neutron energy(MeV)
A(15MV)	1	1.02	0.55
	2	0.98	0.50
	3	0.79	0.40
	Maze	0.16	0.02
B(18MV)	1	1.21	0.65
	2	0.95	0.50
	3	0.56	0.25
	Maze	0.15	0.02
C(10MV)	1	0.98	0.50
	2	0.77	0.40
	3	0.33	0.15
	Maze	0.12	0.02
D(18MV)	1	0.81	0.50
	2	0.63	0.35
	3	0.53	0.25
	Maze	0.17	0.02
E(16MV)	1	0.76	0.40
	2	0.55	0.25
	3	0.30	0.15
	Maze	0.11	0.02
Siemens PRIMUS(15MV)	1	1.04	0.50
	2	0.57	0.20
	3	0.45	0.18
	5	0.44	0.17

The Au activation analysis by using Canberra GR1519 N-type HPGe shows three peaks with energy of 411.8, 355.7 and 333 keV; that are due to activated ^{198}Au and ^{196}Au through reactions ^{197}Au(n, γ)^{198}Au and ^{197}(γ ,n)^{196}Au, respectively. It demonstrated that photoneutrons also exist at isocenter.

P_2O_5 powders were counted for $^{31}P(n,p)^{31}Si$ and $^{31}P(n,\gamma)^{32}P$ β rays after 1h and 24h of irradiation with field size 40 x 40 cm^2, dose rate 500 MU/min and dose 50 Gy. The result of counting by Insta Gel liquid scintillator shows that fast neutron fluence, Φ_F, is 1.745 x 10^4 n cm^{-2} s^{-1}, and slow neutron fluence, Φ_{th}, is 1.258 x 10^5 n cm^{-2} s^{-1}. According to AAPM Report 19, the fast and slow neutron dose conversion factors are 2.477 nGy min^{-1} per n cm^{-2} s^{-1} and 2.4 pGy min^{-1} per n cm^{-2} s^{-1}, respectively (6). Thus the fast and slow neutron absorbed doses are 4.310 x 10^{-5} Gy min^{-1} and 3.019 x 10^{-7} Gy min^{-1}, respectively. The ratio of neutron contamination to x-ray dose at isocenter is 0.00087%, which is one order less that the ratio outside the field. This means that neutron transmission factor for the head is larger than x-ray.

The Q value, neutron per Gy-x of linac, according to equation (1) was calculated as 0.20 x 10^{12} n per Gy-x, which is less than Varian 1800 and GE Saturne 41, as listed in Table 2, with the same energy 15MV. The Q value increases as photon energy increases, and is related to types of linacs and their structure designation. Here in Table 2, shows that Varian series and GE series are much photoneutron contaminated which may be due to their complex beam modulated system, including dynamic wedge, MLC, collimator, etc.

Table 2. Photoneutron source strength of various medical linear accelerators (3)

Manufacturer	Type	Stated MeV*	Q(nertrons per Gy-x)
Siemens	**Primus**	**15**	**0.20 x 10^{12}**
Siemens	KD	20	0.92 x 10^{12}
Varian	1800	18	1.22 x 10^{12}
Varian	1800	15	0.76 x 10^{12}
Varian	1800	10	0.06 x 10^{12}
Philips	SL-25	22	2.37 x 10^{12}
Philips	SL-25	17	0.69 x 10^{12}
GE	Saturne 43	25	2.40 x 10^{12}
GE	Saturne 43	18	1.50 x 10^{12}
GE	Saturne 41	15	0.47 x 10^{12}
GE	Saturne 41	12	0.24 x 10^{12}

CONCLUSION

The measurement of photoneutron in the vicinity of Siemens Primus shows that:

(1) The shielding design for photon of medical linear accelerator is also effective for photoneutron produced by high energy photon itself.

(2) The mean energy of the photoneutron decreases as the distance to isocenter increases and no significant relation to types of linear accelerator. The mean photoneutron energy is 0.02 MeV at maze, which is much less that in treatment room with energy of 0.2 to 0.6 MeV.

(3) The photoneutron source strength at isocenter, Q (nentrons per Gy-x), for Siemens Primus of energy 15MV is 0.20 x 10^{12}, which is less than Varian 1800 and GE Saturne with the same photon energy.

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