Effect of Secondary Induced Radiation: An Observational Study

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Abstract: ***Measurable radiation level near the treatment head of medical electron linear accelerator (LINAC) and in its surrounding is observed due to induced activity, exposing therapy staff to unwanted radiation dose. A study has been done to reduce the exposure to lower level. 2D, 3DCRT and IMRT pelvic irradiation were studied which was planned with 15 MV photon beam and also systematic study was carried out to quantify the radiation levels near LINAC head for planned beam delivery of 200, 400, 600, 800, 1000, 1500 Monitor Units for field sizes 10 x 10 cm^2, 20 x 20 cm^2, 30 x 30 cm^2 , 40 x 40 cm^2 . All measurements were carried out to quantify the radiation level near LINAC head. The dose received by radiation therapists was estimated. The highest personal dose received by radiation therapist was estimated at 5.2 mSv/y due to IMRT pelvic irradiation. The potential hazard to staff from induced activity in the use of high energy photon beams was considered to be very low and no specific actions are considered necessary.***

Keywords: High energy photons, Induced activity, Radiation exposure, IMRT

1. Introduction

High Energy Photon beams have clinical use for treatment of deep seated tumors. However, they induce undesirable photonuclear and electronuclear reactions that produce neutrons and radio-isotopes. Neutron production increases with photon energy and the induced radioactivity depends on the neutron radiation level [1]. This phenomenon induces potential exposure for radiation therapists due to neutron, gamma and beta radiations emitted from decay of activation products [2]. When the photon beam energy is higher than 8-10MV, components of the LINAC head such as X ray target scattering filter, monitor chamber, cooling system, collimation system and multi leaf collimator (MLC) gets activated by photo-neutrons. Isotopes that are neutron -deficient will likely undergo decay by positron emission or electron capture, and isotopes with excess neutron will likely decay by beta emission. Since many of these decays result in isotopes in an excited state, gamma rays are emitted that can cause exposure to those present in the treatment room. By using gamma spectroscopy methods, variety of radio isotopes such as ^{24}Na ,^{28}AI ,^{54}Mn, ^{56}Mn, ^{57}Ni, ^{53}Fe, ^{59}Fe, ^{58}Co, ^{62}CU, ^{64}CU, ^{82}Br, ^{122}Sb and ^{187}W have been identified by a number of investigators in and around the LINAC head. It has also been reported that two short lived radio nuclides (^{28}Al with T½ = 2.3 min and ^{62}Cu with T½ = 9.7 min) and two long lived radio nuclides (^{187}W with T½ = 23.7 h and ^{57}Ni with T½ = 36 h) are the main contributors of the radiation level around the LINAC head [1, 3]. Different treatment techniques also have an effect on induced radioactivity. Advanced radiotherapy techniques on one hand like 3DCRT(three dimensional conformal radiotherapy) and IMRT (intensity modulated radiotherapy) , provide high conformity for treatment targets and reduce unnecessary radiation doses to surrounding healthy tissues but increases beams on time for the same dose compared to conventional techniques. For longer irradiation times, more secondary neutrons are generated, hence increasing the amount of induced radioactivity [4]. A systematic measurement of radiation level near LINAC head was conducted with different treatment techniques commonly used for patient treatments in our hospital. In addition to this, radiation levels due to different field size with increase of monitor units were also measured. LINAC head was selected to quantify the radiation dose to radiotherapy technologists because they were usually stand at this location during removal/set up of the patient for treatment and for changing the treatment accessories required for the treatment of patient.

2. Materials and Methods

All the measurements were carried out on dual photon energy Elekta Synergy. Radiation level near the LINAC head (point H) was measured by using digital survey monitors shown in **figure 1**. This monitor contains Geiger Muller counter .The survey monitor was operated in dose rate mode for measuring the radiation level at intended points. Radiation level was measured in morning hour before clinical use and during day hour.

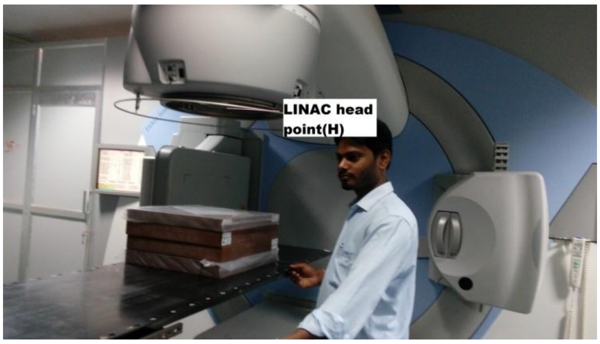

Figure 1: LINAC head (point H) where radiation level was measured after termination of beam

In this study, three treatment approaches were assessed 1) 2D (conventional techniques) with 15 MV posterior-anterior (AP-PA) pelvic irradiations 2) 3DCRT with 15 MV (two anterior posterior and two lateral fields) and 3) IMRT with 15 MV 9 fields pelvic irradiation. Three treatment plans were delivered to slab phantom. 2D pelvic irradiation plan was delivered with two field (AP -PA) field size of 15 x 15 cm^2 and separation of 25cm. A dose prescription of 2gy per fraction was given. For each fraction in conventional technique, 260MU was delivered with 400 dose rate. The 3DCRT plan was delivered to the pelvic phantom with 229 MU per fraction. The IMRT plan was delivered with 9 fields with 590 MU per fraction. Measurements were taken after completion of treatment and repeated five times for the three techniques. The measurement of the dose rates was recorded instantly after the beam had stopped. The dose rate was measured with survey meter and recorded. After each data recording, a time delay of 10 min elapsed before the start of the next experiment to allow for clearance of long lived radio isotopes. Radiation levels due to different field size (10 x 10 cm^2, 20 x 20 cm^2, 30 x 30 cm^2) with increase of monitor unit were also recorded with 400 dose rate.

3. Results

The radiation level was measured at point H for different plans shown in **Table 1.** The radiation level measured immediately after beam off was 200 µR/h for 2D, 210 µR/h for 3DCRT and 250 µR/h for IMRT pelvic irradiation during day hour. During morning hour radiation level immediately after beam off were 80 µR/h for 2D, 81 µR/h for 3DCRT and 131 µR/h for IMRT. These values show that radiation level due to induced activity increases in day hour.

Figure 2, 3 and **4** represents measured radiation levels from induced activity at point H for different plan. Although the radiation level was higher for IMRT but value was less than 1 mR/h (10 µSv/h). Figure 2, 3 and 4 also indicates that radiation level was measurable up to 20 minutes after beam delivery during day hour. Radiation level reached to background after 5 minutes for 2D and 3DCRT beam delivery during morning hour. But in case of IMRT it takes 20 minute. In general, radiotherapy technologist's work for about 8 h/day 5 days/week and 52 week/year corresponds to 5.2 mSv/y to radiation therapists while entering the treatment room immediately after IMRT plan delivery.

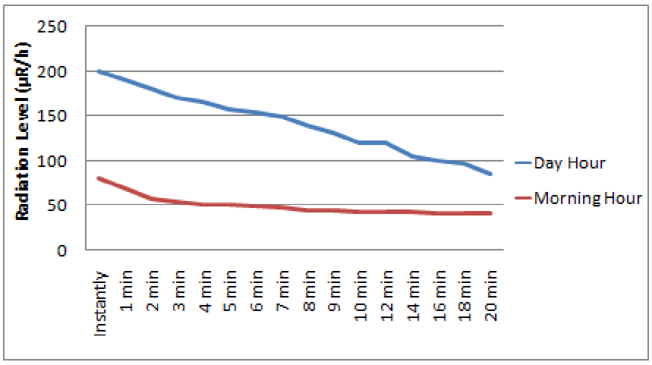

Figure 2: Measured radiation level due to 2D irradiation

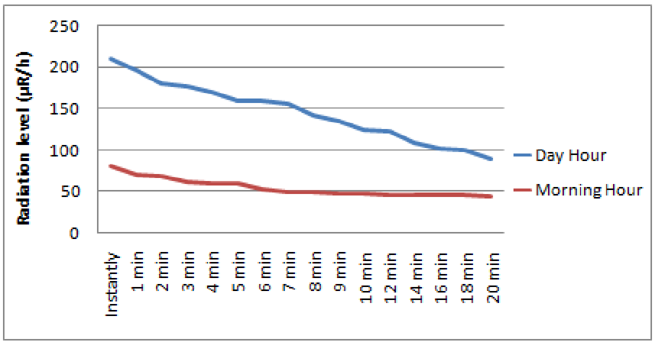

Figure 3: Measured radiation level due to 3DCRT irradiation

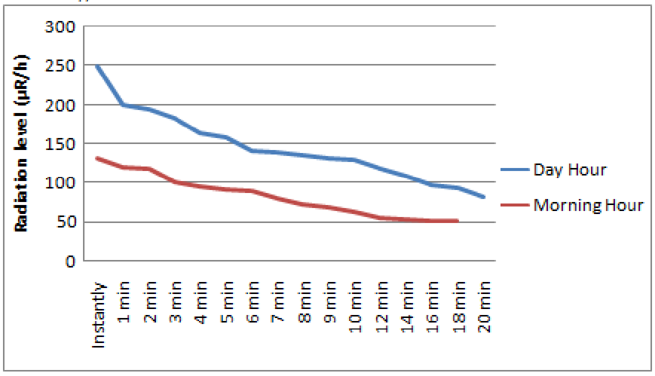

Figure 4: Measured radiation level due to IMRT

Table 2 represent radiation level near LINAC head due to induced activity after termination of irradiation by 15 MV X-ray beam for different field size and monitor units. The radiation level was measurable even after 1 min of termination of beam but value was less than 1 mR/h. It has been observed that with increase of field size and monitor unit radiation level increases. For field size 30 x 30 cm2 and 1500 MU radiation level was 0.36 mR/h instantly after termination of beam. Even after 1 minute, radiation level was 0.27 mR/h.

Figure 5 and **6** represents the bar diagram of the measured radiation levels from induced activity at point H for different field size and monitor unit. Figure shows that with increase of MU, radiation level gradually increases and there is the chance of further increase of radiation level at end of the day.

Table 1: Measured radiation level near LINAC head for 2D, 3DCRT

Pelvic plan → / Entry Delay ↓	2D (μR/h)		3DCRT(μR/h)		IMRT(μR/h)		Annual Dose due to IMRT (mSv/y)
	Day Hour	Morning Hour	Day Hour	Morning Hour	Day Hour	Morning Hour	
Background	42	42	46	45	43	43	----
Instantly	200	80	210	81	250	131	5.2
1 min	190	69	196	70	200	120	4.1
2 min	180	58	181	68	194	118	4.0
3 min	171	54	176	62	183	100	3.8
4 min	165	52	169	60	165	96	3.4
5 min	157	52	160	59	158	91	3.2
6 min	155	50	159	52	142	90	2.9
7 min	150	49	155	50	139	80	2.8
8 min	140	45	142	49	136	73	2.8
9 min	132	45	134	47	132	68	2.7
10 min	121	44	124	48	129	64	2.6
12 min	120	43	122	45	119	56	2.4
14 min	105	43	108	46	108	54	2.2
16 min	100	42	102	45	97	52	2.0
18 min	98	42	100	45	94	52	1.9
20 min	86	42	89	45	82	50	1.7

Table 2: Measured radiation level near LINAC head

Monitor Unit		200		400		600		800		1000		1500	
Field size Cm^2	Background (μR/h)	Instantly (μR/h)	After 1 min (μR/h)	Instantly (μR/h)	After 1 min (μR/h)	Instantly (μR/h)	After 1 min (μR/h)	Instantly (μR/h)	After 1 min (μR/h)	Instantly (μR/h)	After 1 min (μR/h)	Instantly (μR/h)	After 1 min (μR/h)
10 x 10	46	95	68	125	103	200	160	230	196	270	200	310	250
20 x 20	43	96	70	142	109	205	163	240	200	310	230	340	264
30 x 30	43	98	73	153	118	210	164	290	210	350	260	360	270

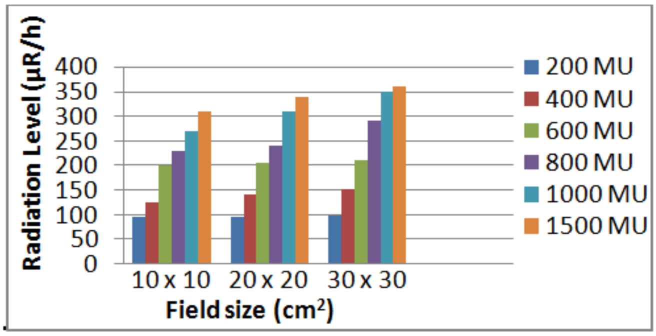

Figure 5: Radiation level instantly after termination of beam

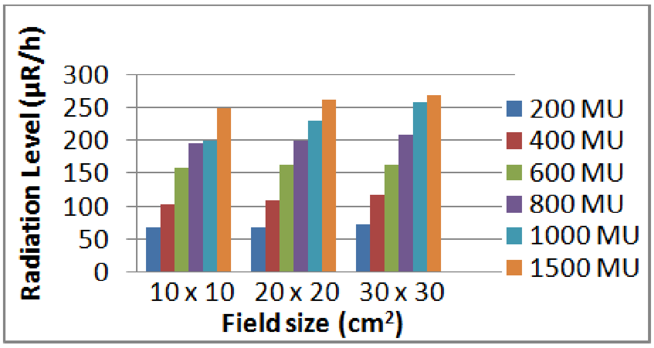

Figure 6: Radiation level interval of 1 Min after termination of beam

3DCRT, IMRT pelvic irradiation

4. Discussion

A number of investigators have been reported on the characteristics and levels of radiation in the treatment room. The type and significance of radioactive species vary depending upon the accelerator, the location in the room in relation to the angle of the accelerator head, the collimator opening, usage of high-energy beams at the hospital, duration of time therapists spend in setting up patients and room construction. Low energy beams are increasingly being used in place of high energy photons in IMRT[5-6]. In addition, all modern accelerators have multi-leaf collimators, and most facilities use these for beam shaping in place of blocks placed on trays at the bottom of the treatment head. Physical wedges, also at the bottom of the treatment head, are increasingly being replaced by dynamic, virtual , or universal wedges that do not require insertion by a therapist[7]. These changes in practice reduce the dose received by therapists due to activation products. A number of methods can be considered to reduce dose to radiation therapy staff by restricting the use of high energy treatment to the latter part of the day to reduce the buildup of activity throughout the day, consideration in delaying entry of staff to the treatment room, moving the table and gantry from the control panel rather than from the pendant at the couch, close the collimators from the control panel before entering and assign pregnant staff to lower energy treatment . Om prakash et al[8] reported that radiation level at point H (CLINAC DMX) even after 1 min of termination of the beam was higher than 1 mR/h except for field size 5 cm x 5 cm and 10 cm x 10 cm for all monitor units and 20 cm x 20 cm for 50

MU. But our finding shows that radiation level in Elekta Synergy was much lower. In our finding highest personal dose received by radiation therapists was 5.2 mSv/y due to IMRT plan delivery which is in accordance to the results of Lavine Ho et al [9]. J Alan Rawlinson et al [10] reported that radioisotope immediately after irradiation was found to be ^{28}AL and quickly disappears and ^{56}Mn dominates. Between 12 to 24 h after irradiation ^{24}Na becomes the major product. Yi Zhen Wang[11] reported that radiation level in morning before any clinical work increases from Monday to Saturday and decreases during the weekend. S. J Thomas [12] reported that dose rate at the isocentre immediately after irradiation is 40 µSv/h. A Almen et al [13] dose rate to the technician was calculated to 2 mGy.

According to highest annual dose estimation 5.2 mSv/y would be received if radiation therapists entered the treatment room immediately after beam off for IMRT. Although the estimated equivalent doses were lower than the maximum permissible dose values, exposure due to induced activation cannot be neglected and it is important to investigate dose reduction strategies when using high energy photon beams. Even though annual doses for all approaches were below maximum permissible dose values i.e. 20 mSv/y[14], radiation therapist should remain alert to protect themselves from unnecessary radiation and limit the equivalent dose to as low as reasonably achievable.

5. Conclusion

Radiation levels due to induced activity were measured near LINAC head for different treatment technique and for different field size for various monitor units. This survey of the measured data indicates that the significant radiation dose is received by the radiotherapy technologist while standing below the LINAC head even after 1 min of termination. But annual doses for all approaches were below maximum permissible dose values i.e. 20 mSv/y. It was also recoded that radiation level was less in morning hour and it was increased in the day, therefore there was a chance to receive unwanted dose at the end of the day. After termination of IMRT and 3DCRT pelvic irradiation, significant radiation levels were recorded up to 20 minute. However it is recommended that radiation therapists wait for as long as possible, but practically it is not possible because of workload. This can be explained by the fact that radiation will never fall to zero and there are always minute amounts of residual radiation in the treatment room. The linear response model of radiation suggests in an increase in risk. Studies of occupational workers exposed to chronic low levels of radiation, above normal background, have shown higher probability with regards to developing leukemia and other Cancer [15]. Therefore it is recommended to decrease the potential risk due to secondary induced radiation by following the dose reduction strategies as suggested above.

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