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Radiation dose to Radiotherapy Technologists due to induced activity in high energy Medical Linear Accelerators

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ABSTRACT: *After executing the high photon beam energy of 15 MV energy, measurableradiation level near the treatment head of medical linear accelerator (LA) and in its surrounding is available due to induced activity generated in photon target and non target materials (cooling tube, flattening filter, monitor chamber , collimating jaws, etc).The generated radiation in the head of LA has the potential of interacting with the radiotherapy technologists if he comes in this region immediately after delivering the planned treatment of 15MV energy. The palnnedstudy has been carried out to measure the radiation levels at and around the isocentre of Medical LA head, the taken is isocentre and 0.5 meter lateral to isocentre for planned beam delivery of 50, 100, 200, 300, 400, 500 and 1000 monitor units (MUs) at field sizes 5×5, 10×10, 20×20, 30×30 and 40×40 cm^2. The measured maximum radiation level at/around LA head, isocentre and 0.5 meter lateral to isocentre after one minute of completion of treatment was 2.93 mR/h (≈ 27.25 μSv/h), 0.98 mR/h (≈ 9.11 μSv/h) and 0.45 mR/h (≈ 4.19 μSv/h)respectively when the radiation treatment was executing for ≤ 500 MUs. However, the levels of radiationat these pointsafter one minute of completion of radiation treatment evaluated4.81 mR/h (≈ 44.73 μSv/h), 1.38 mR/h (≈ 12.83 μSv/h) and 0.63 mR/h (≈ 5.86 μSv/h) respectivelywhen the radiation treatment was executing for 1000 MUs. It was also seen that the radiation level due to induced activity increase with increasing exposure field size and number of MUs and shows saturation characteristics when the field size approaches to 30×30 cm^2.This study indicates that area near to LA head is the main region where radiation level due to induced activity is higher than the instant dose limit (7.3 μSv/h) in most of cases after delivering 15 MV beams, so standing below the treatment head of the LA should be avoided for next 9.5 minutes after delivery of plan with 15 MV beams. In case of delivering about 1000 MUs, radiation worker should enter in the treatment room at least after 1 minute and avoid standing at above said position for next 13 minutes.*

Key words: *Linear accelerator, induced activity, radiation level, occupational safety, 15 MV*

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I. Introduction

Treatment of cancer patients with Radiotherapy getsexecuted by using photon and electron beams generated by medical electron linear accelerator (LA). Radiotherapy technologists are involved in treatment delivery procedure and they are present at the linear accelerator control console station while the beam is on and inside the treatment room for removal/setup of patient while the beam is off. Generally, radiotherapy technologists work for about eight hours per day and five days per week.

At the time ofthe photon beam energy is higher than 8-10 MeV,components of the LA head such as x-ray target, flattening foil, monitor chamber, cooling systems, collimating jaws and multileaf collimator (MLC) gets activated by photo-neutrons.[1]As suchinduced activity measurable radiation is available at and around the LA head even when the beam is off. This radiation level emits due to gamma rays coming from photo disintegration and neutron capture reactions.[2] By using gamma spectroscopy methods,variety of radio-isotopes such as ^{24}Na, ^{28}Al, ^{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 at and around the LA head.[1,3] It has also been assessed that two short-lived radionuclides (^{28}Al with $T_{1/2}$=2.3 minand ^{62}Cu with $T_{1/2}$=9.7 min)and two long-lived radionuclides(^{187}W with $T_{1/2}$=23.7 h and ^{57}Ni with $T_{1/2}$=36 h) are significant contributors of the radiation level at and around isocentre.[1,2]Most of the investigators have reported their measurements of radiation level near LA head and isocentre for relatively large number of MUs (1000, 2000, 3000 MUs) which does not measure the realistic condition of clinical operation of the accelerator for the patient treatment. The planned measurements of radiation level near LA head, isocentre and 0.5 meter lateral to isocentre were conducted selecting the number of monitoring units commonly used for patient treatments in our hospital (50, 100, 200, 300 etc.). The measurement point from 0.5 meter lateral to isocentre was taken to quantify the radiation dose to radiotherapy technologists because radiotherapy technologists usually stand at this location during removal and set-up of the patient for the treatment and for changing the treatment accessories required for the treatment of the taken patient.

II. Materials and Methods

Linear accelerator (LA) Varian Clinac DMX (Varian medical systems, Palo Alto, CA) is used in our hospital for treatment of cancer patients. The treatment head of this LA contains tungsten primary and secondary collimators, tungsten alloy x-ray target, tungsten alloy flattening filter, aluminium MLC carriage box, tungsten MLC leaves, copper cooling pipes in the head andfour compartment monitor chamber mainly containing copper.

Radiation levels at and around LAhead (point – H), isocenter(point – I) and 0.5 meter lateral to isocenter (point – LI) of LAwas measured by using digital contamination monitor(Micro, Type: CM710P, Pancake,NUCLEONIX Systems Pvt. Ltd., Hyderabad, India) capable of measuring the radiation levels from beta and gamma rays. This contamination monitor contains halogen quenched Geiger Muller counter and, has the measuring range of 0 – 2000μSv/h (0-200 mR/h). The stated calibration accuracy of this contamination monitor is ±15%.The contamination monitor was operated in dose-rate mode for measuring the radiation levels at intended points.

For the experimental measurement of radiation levels, the medical LA was operated in 15 MV photon beam mode for 50 MU at the dose rate of 400 MU/minute for a field size of 5x5 cm^2 and the radiation levels due to induced radio-activity at points H, I and LI (Fig. 1) were recorded immediately after irradiation and at one minute after the irradiation. The measurements of radiation levels at these points were repeatedly performed by operating the LA for 100, 200, 400, 500 and 1000 MUs. Similarly, measurements of radiation levels were also repeatedly performed for field sizes of 10×10, 20×20, 30×30 and 40×40 cm^2. For plotting decay curve, measurements for 500 and 1000 MUs at 20x20 cm^2 were taken at 15 seconds time interval till the saturation in radiation level achieved.Meter reading of contamination monitor in the console before every measurement was zero. Whereas the constant time gap of 30 minutes was maintained between two consecutive exposures. The whole measurements were taken during the period of 15 days, between 3 hours daily in the morning session from 6 AM to 9 AM. The average room temperature and atmospheric pressure were 19.8° C and 952.3 mbar respectively.

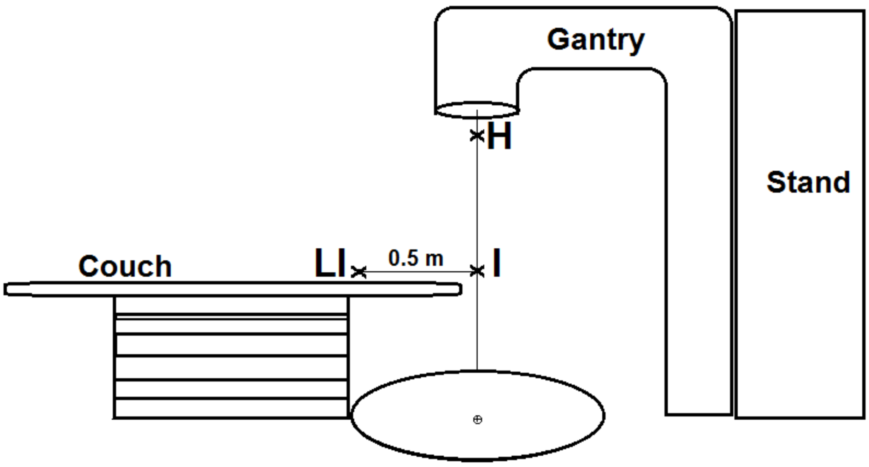

Fig. 1: Schematic diagram of the medical electron linear accelerator (LA)showing the locations of the three points [LA head (H), at isocenter (I) and 0.5 m lateral to isocentre (LI)] where radiation levels were measured instantly and one minute after the irradiation.

III. Results and Discussions

The radiation levels at the points of H, I and LI due to induced activity after executing the x-ray beam of energy 15 MV, was measured as shown in table 1, 2 and 3.

Table 1: Radiation level measured at LA head at the time ofbeam delivery and at interval ofone minute

Field size (cm²)	Radiation Level (mR/h) for													
	50 MU		100 MU		200 MU		300 MU		400 MU		500 MU		1000 MU	
	Instantly	After 1min	Instantly	After 1min	Instantly	After 1min	Instantly	After 1min	Instantly	After 1min	Instantly	After 1min	Instantly	After 1min
5×5	0.14	0.01	0.19	0.09	0.27	0.20	0.27	0.16	0.65	0.34	1.07	0.67	1.57	1.17
10×10	0.30	0.14	0.42	0.21	0.60	0.26	0.65	0.43	1.04	0.76	1.51	1.24	3.03	2.15
20×20	0.73	0.57	0.89	0.83	1.30	0.85	1.46	1.21	2.25	1.99	2.88	2.51	4.17	3.72
30×30	1.02	0.84	1.14	1.00	1.68	1.28	1.69	1.27	3.04	2.38	3.44	2.81	5.79	4.72
40×40	1.05	0.83	1.13	0.90	1.46	1.16	1.99	1.22	2.69	2.14	3.39	2.93	5.59	4.81

***instantly means 15 seconds after beam off, as this much time is needed to reach at measuring point from console**

Table 2: Radiation level measured at the isocenter just at the time of beam delivery and at the interval of 1 minute

Field size (cm²)	Radiation Level (mR/h) for													
	50 MU		100 MU		200 MU		300 MU		400 MU		500 MU		1000 MU	
	Instantly	After 1min	Instantly	After 1min	Instantly	After 1min	Instantly	After 1min	Instantly	After 1min	Instantly	After 1min	Instantly	After 1min
5×5	0.04	0.02	0.06	0.03	0.22	0.16	0.31	0.24	0.52	0.38	0.62	0.51	1.09	0.73
10×10	0.20	0.15	0.27	0.18	0.36	0.21	0.49	0.36	0.72	0.55	0.83	0.72	1.24	0.82
20×20	0.37	0.29	0.47	0.34	0.54	0.35	0.60	0.49	0.86	0.69	1.08	0.98	1.630	1.34
30×30	0.44	0.37	0.45	0.38	0.56	0.42	0.72	0.69	0.91	0.72	1.13	0.87	1.78	1.38
40×40	0.51	0.48	0.53	0.50	0.63	0.54	0.77	0.57	0.98	0.84	1.09	0.98	1.71	0.97

***instantly means 15 seconds after beam off, as this much time is needed to reach at measuring point from console**

Table 3: Radiation level measured at 0.5m lateral to isocenter at the time of beam delivery and at the interval of one minute

Field size (cm²)	Radiation Level (mR/h) for													
	50 MU		100 MU		200 MU		300 MU		400 MU		500 MU		1000 MU	
	Instantly	After 1min	Instantly	After 1min	Instantly	After 1min	Instantly	After 1min	Instantly	After 1min	Instantly	After 1min	Instantly	After 1min
5×5	0.00	0.00	0.03	0.01	0.15	0.08	0.25	0.17	0.35	0.25	0.45	0.35	1.02	0.60
10×10	0.14	0.10	0.17	0.07	0.30	0.15	0.32	0.23	0.45	0.30	0.62	0.45	1.08	0.60
20×20	0.15	0.08	0.16	0.11	0.21	0.18	0.37	0.34	0.55	0.36	0.58	0.39	0.87	0.60
30×30	0.17	0.11	0.24	0.22	0.28	0.20	0.33	0.27	0.43	0.37	0.54	0.33	0.96	0.63
40×40	0.21	0.13	0.19	0.14	0.30	0.17	0.40	0.27	0.49	0.36	0.54	0.41	1.40	0.59

***instantly means 15 seconds after beam off, as this much time is needed to reach at measuring point from console**

Figure 2 shows the increase in radiation levels at H, I and LI with increasing MUs at 10×10 cm^{2}standard field size.

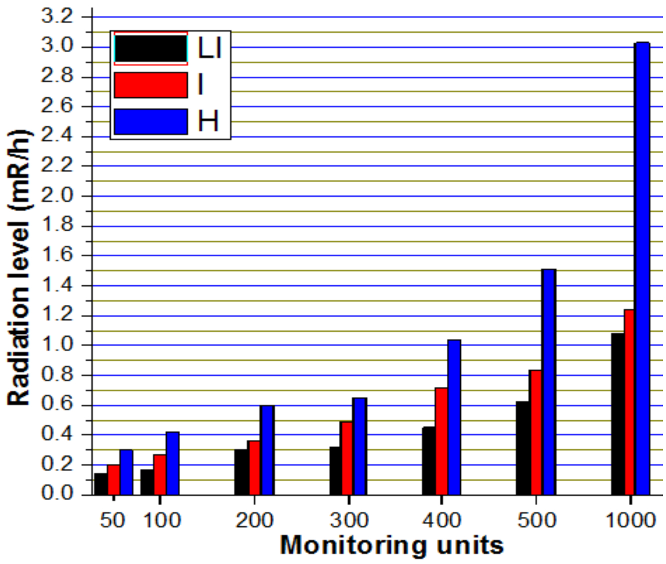

Figure 2: Radiation level at H, I and LI versus MUs at 10×10 cm^2 standard field size.

***Calculation for radiation dose received by radiotherapy technologist in a single year*:**

In general maximum of 15-20 cancer patients are treated with plans having 15 MV photon beams at our centre treating average 50-60 patients per day.We use 15 MV in 3 – dimensional conformal radiotherapy (3DCRT) plans only so all plans created with 15 MV at our centre are 3DCRT. For the worst case, assume 20 patients are being treated by plans with 15 MV beams (each plan with maximum of 500 MU) and next patient with brain/ head-and-neck (H&N) case has to be setup after delivery ofevery plan with 15 MV beams. Also assume that the opened field size while setup is 30x30 cm^2 and during the part of setup technologist standat position as shown in figure 4 (a) for maximum of 1 minute, then annual dose received by technologist's head will be as follows;

Dose rate at H after delivering 500 MU by 15 MV beam atfield size30x30 cm^2(from table 1) = 3.44 mR/h

So, annual dose = 3.44 mR/60min × 20 min (in a day) × 5 days (in a week) × 52 weeks (in a year)

= 298.13 mR

In case of x-radiation and soft tissue, 1 R would be approximately 9.3 mSv[4], so 324.13 mR is approximately equivalent to 2.77 mSv.

As per guidelines of the Radiation Safety Code, Atomic Energy Regulatory Board (AERB) [5], radiation dose limits for radiation workers are as follows;

- an effective dose of 20 mSv/y averaged over five consecutive years (calculated on a sliding scale of five years)
- an equivalent dose to the extremities (hands and feet) of 500 mSv/y
- an equivalent dose to the skin of 500 mSv/y

And, as per the International Commission on Radiological Protection (ICRP 2011)[6], the new radiation dose limit for lens of eyes is 20 mSv/y.[7]

So, even if the same technologist involve in treating all above mentioned hypothetical number of patients for one year even then the dose due to induced activity is much lesser than the annual dose constraint.

Instantaneous dose rate (IDR):

As per Institute of Physics and Engineering in Medicine (IPEM) guidance[8] on radiation levels definining controlled and supervised areas, area with IDR > 2000 µSv/h, > 7.5 µSv/h and < 7.5 µSv/h are considered as controlled, supervised and unsupervised areas respectively. For 6 MV linear accelerator facility IDR should be limited to 7.5 µSv/h.[8- 10] For 18 MV linear accelerator facility the dose in any hour limit is 20 µSv.[10]For x-radiation and soft tissue 7.5 µSv ≈ 0.81 mR and 20 µSv ≈ 2.15 mR. Although these above doses are design dose limits, however considering these dose limits the IDR at LA head can be evaluated for the safety of technologists (while treating patients by plans with 15MV beam) and physicists (while doing dosimetric work for 15MV).

From the tables 1, 2 and 3, we analyzed radiation levels at positions H, I and LI as follows;

H:At field size20x20 and above, radiation level is more than 0.81 mR/h even after one minute of delivering 50MUs and above (except for 50 MUs at 20x20 cm^2). Radiation level is more than above said value for 1000 MUs at 5x5 cm^2 and 10x10 cm^2 and for 500 MUs at 10x10 cm^2 even after one minute. And it is also higher for 400 MUs at 10x10 and for 500 MUs at 5x5 cm^2 instantly after dose delivery.

I:Radiation level is more than 0. 81 mR/h even after 1 minute of delivering 400 MUs at 40x40 cm^2, 500 MUs at 20x20 $cm^2$and above F.S. and 1000 MUs at 10x10 cm^2 and abovefield size. The radiation level is higher instantly after delivering 400 MUs at 20x20, 500 MUs at 10x10 and 1000 MUs at 5x5 cm^2.

LI:This position is safe except instantly after delivering 1000 MUs.

So H and I region should be considered supervised for all radiation workers whenever radiation level live higher than the above mentioned instant dose limit. Generally number of MUs delivered by any 3DCRT treatment plan with 15MV beams remain below 500 although for bulky patients with pelvic cases Intensity modulated radiotherapy (IMRT) is also done with 15 MV by many of the Physicists [11,12] and more than 800 – 1000 MUs are delivered by single IMRT plan. And while doing dosimetric work like taking profile and PDD, the number of MUs remains up to 1000. We can see in figure 4 (a) that if 500 MUs delivered at field size 20x20 cm^2 then the radiation level at position Hcome below 0.81 mR/h after 9.5 minutes, similarly we can see in figure 4 (b) that if 1000 MUs delivered at same field size then radiation level comes below 0.81 mR/h after 13 minutes.

Figure 3: Technologist's standing positions during setup of (a) Brain and H&N cases (b) Chest and pelvic cases

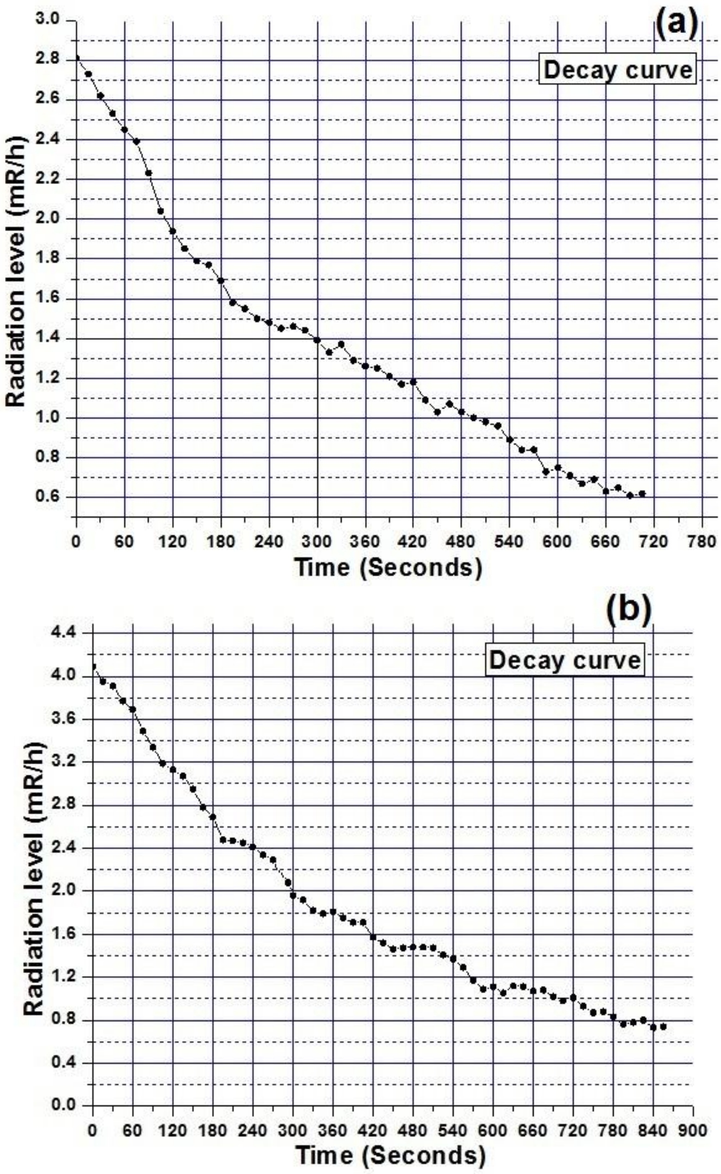

Figure 4: Decay curves of radiation level at point H due to induced activity after delivering (a) 500 MUs and (b) 1000 MUs

Completing treatment of the first patient, RT technologist goes inside and set up the next patient by standing at the position as shown in figure 3 (a) for head-and-neck and brain cases and at position as shown in figure 3 (b) for chest and pelvis cases. The estimated time taken by technologist to reach at couch from console is ≤ 15 seconds and, that the delivery of any plan of 15 MV beams, the position shown in figure 3 (a), should be avoided.

From the decay curves as shown in figure 4 (a) and (b), we can see that the half life in both the curves is about 5 minutes and since the mean half life of ^{28}Al ($T_{1/2}$ = 2.3 min) and ^{62}Cu ($T_{1/2}$ = 9.7 min) is 6 minutes so these decay curvesconcurred with the results ofAlmen *et al* [1]who described that contribution of γ-rays from ^{28}Al and ^{62}Cu is dominant in dose rate immediately after beam off. Contribution of γ-rays from ^{187}W ($T_{1/2}$ = 24 h) and ^{57}Ni ($T_{1/2}$ = 36 h) is also important and the absorbed dose rate at isocentre is observed about twice of the treatment couch.

Observing these radionuclides and their half lives at the time interval of 30 minute was kept between two measurements so that activation of Al and Cu due to first exposure could not contribute significantly to the measurement after next exposure to main value accuracy. However, contribution from ^{187}W and ^{57}Ni can't be avoided due to their long half lives, also it should not be avoided as in the routine radiotherapy schedule LA runs from morning to evening and so time interval between LA switch-on time and switch off is very less than $T_{1/2}$ of ^{187}W and ^{57}Ni, and radiation dose contribution from these radionuclides to the RT technologists can't be avoided even if he stands at position shown in figure 3 (a).

IV. Conclusion

The measured maximum radiation levels at and around LA head, isocentre and 0.5 meter lateral to isocentre after one minute of completion of treatment were 2.93 mR/h (≈ 27.25 µSv/h), 0.98 mR/h (≈ 9.11 µSv/h) and 0.45 mR/h (≈ 4.19 µSv/h) respectively when the accelerator was performed for less than 500 MUs. Whereas the radiation levels at these locations after one minute of completion of treatment were found 4.81 mR/h (≈ 44.73 µSv/h), 1.38 mR/h (≈ 12.83 µSv/h) and 0.63 mR/h (≈ 5.86 µSv/h) respectively when the accelerator was performed for 1000 MUs. It was also evaluated that the radiation levels due to induced activities, increases with increasing field size and number of MUs and shows saturation characteristics when the field size approaches to 30×30 cm^2.

This study clearly shows that at and around to LA head is the main area where radiation level due to induced activity is higher than 0.81 mR/h (7.3 µSv/h) in the most cases after executing 15 MV radiation beams, sostanding at the position as shown in figure 3 (a) should be avoided for next 9.5 minutes after delivery of plan with 15 MV radiation beams. In the case of delivering IMRT plan with 15 MV beams, RT technologist should enter in the treatment room after 1 minute and avoid standing at above recorded position for the next 13 minutes. While doing dosimetric work, the Physicist should also follow these above safety instructions.

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