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Measurement of Truebeam® Head-Leakage by Optically Stimulated Uminescence/Track-Etch Passive Detectors

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Abstract: ***This work was performed in order to measure the photon and neutron head-leakage values of the TrueBeam® (TB) accelerator. Measurements are compared with the data provided by the manufacturer for TB as well as Clinac.Four higher photon energies (10MV, 10MV FFF, 18MV and 20MV) and electron energy (22MeV) are considered in this study. The electron energy used in this study was the maximum available in this machine. Optically Stimulated Luminescence (OSL) Dosimeters are used for photon head-leakage measurements. Neutron component of the head-leakage was measured using track-etch (CR-39) detectors. Both photon and neutron head-leakage values for TB machine was measured using OSL and track-etch, respectively. These results were compared with the standard values provided by the manufacturer for both TB and Clinac. The study indicates that the higher neutron head-leakage once moved towards the 20MV range of photon energy. Also, the lower head-leakage values were recorded for flattening filter free beam (10MV FFF). It was observed that the photon head leakage value for Clinac was higher, and the neutron head-leakage value was found to be slightly less than the TB values.***

Keywords : TrueBeam®, Head-leakage, neutron, track-etch detectors, OSL detectors.

I. INTRODUCTION

Head-leakage measurements at clinical linear accelerators for radiotherapy are aimed for protecting patients, radiation workers, hospital staff and sometimes even common public. Once the beam was on, the radiation inside the therapy room consists of primary, scattered, and head-leakage photon radiation as well as neutrons [1]. Numerous studies are already available in the literature for measurement of the primary, scattered and leakage radiation [2,3]. However, this study, along with the measurement of TrueBeam® values, compares the results with older linac models (Clinac) as well. Varian made a considerable change in the head design once they redesigned the current Clinac treatment head for TrueBeam® machine [4]. Since the scatter and leakage parameters are heavily depended on the shielding materials and head design, it is crucial to understand the specific values for each accelerator model [5]. International Electrotechnical Commission (IEC) 60601-2-1 international standard recommends that for photons, the head-leakage limits for out beam-patient plane are maximum 0.2% and average 0.1% [6]. For neutrons, the head-leakage limit for out-beam in the patient plane are maximum of 0.05% and an average 0.02%. The comparison was with respect to the dose at d_{max} for a 10x10 cm^2 field at the central axis for each energy, represented as dose fraction. So, the aim and reason for this study are to verify the head-leakage, both photon and neutron, values for TrueBeam® machine.

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II. MATERIALS AND METHODS

A. *Parameters and calculation formulae used in this study*

The dose comparison throughout this study is performed with respect to the dose at d_{max} for a 10x10 cm^2 field at the central axis for each energy, represented as '**Percentage Dose fraction (% Dose fraction)**'. The formula used to calculate the Relative Dose is shown below.

$$Relative\ Dose\ (\%) = \frac{(Dose\ at\ off\ axis\ distance\ point)}{(Dose\ at\ reference\ point)}\ X\ 100$$

The formula used to calculate **Percentage Dose Difference (% Diff)** is shown below.

- Measured vs Vendor Provided:

$$\%\ Dose\ Diff = \frac{(Measured\ value - Vendor\ Provided\ value)}{(Measured\ value)}\ X\ 100$$

The error analysis in this study is performed using the parameter **Standard Error of the Mean**. The formula used to calculate the Standard Error of the Mean is shown below:

$$Standard\ Error\ of\ the\ Mean = \frac{Standard\ Deviation}{Sqrt\ of\ Observations}$$

B. *Measurements*

The head-leakage measurements were made for all high X-ray energies and the highest electron energy. Dose fraction for leakage neurons was measured at two types of locations. 1) In-Beam at the isocenter. 2) Out-Beam at 23 locations in the patient plane. Dose fraction for leakage photons was measured only at Out-beam at 23 locations. In-beam at the isocenter measurements were taken using the field sizes 10x10 cm^2 and jaws fully closed (0.5x0.5 cm^2). Out-beam measurements for 23 locations were taken with jaws fully closed (0.5x0.5 cm^2). All the measurements are made in the patient plane, outside the area of the circle of 50cm radius from isocenter, and this circular region was marked as aria M in Figure .**1**. Energy considered for this study, the thickness of the buildup material used (d_{max} value), and the MU used for irradiation are given in

Table 1. All the measurements are taken in a single exposure.

Table 1: Energy, d_{max} and MU values

Mode	10MV	10FFF	18MV	20MV	22MeV
d_{max} (cm)	2.5	2.5	3.3	3.5	3.5
MU	5000	10000	2500	2500	20000

1) *Measurement setup: Out-beam at 23 locations in the patient plane*

To measure leakage radiation in the patient plane, 23 points of measurement are chosen at radii 50cm, 100cm and 150 cm from the isocenter (Figure .**1**). IEC 60602-2-1 shows 24 points of measurements for averaging leakage radiation. One measurement point between point T and S was omitted due to interference with the stand and machine gantry. Measurements were taken at 100 cm Source to Detector Distance (SDD) with buildup. A wooden 'spoke' board (Figure .**1**) was used to place detectors. Small square pieces of water equivalent material are used as a build up with a thickness corresponding to d_{max} per energy.

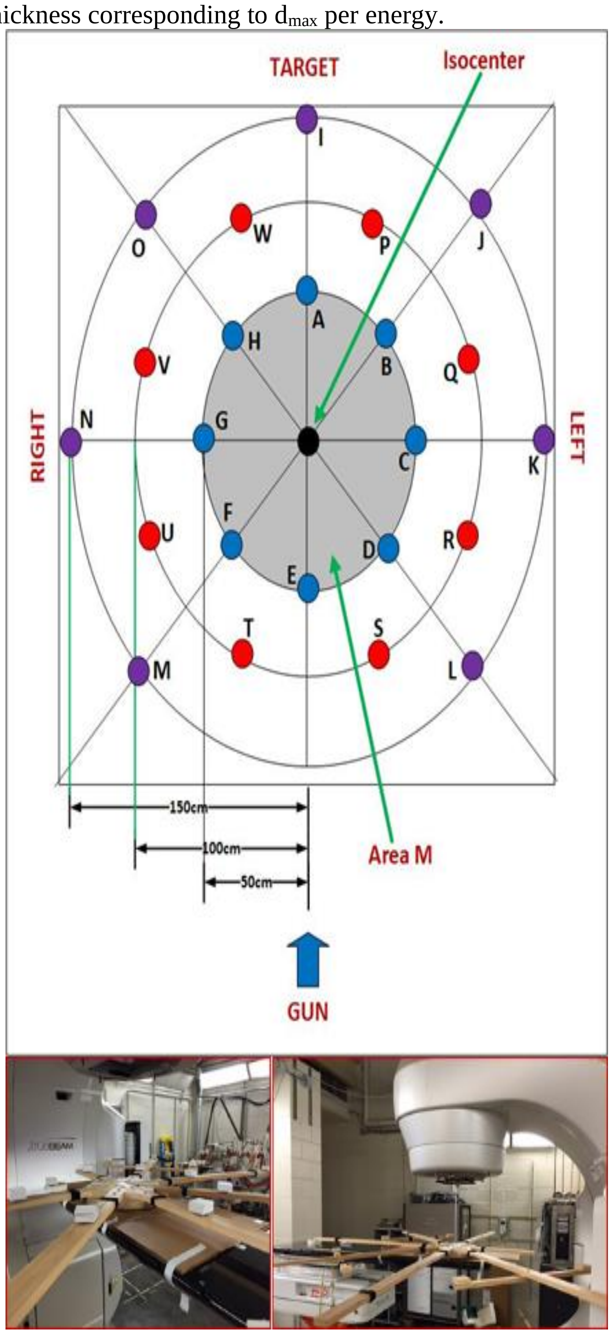

Figure .1 Measurement Locations: Out-Beam in the patient plane (23 points) and Measurement setup.

C. *Dosimeters*

Dosimeters used in this study was Luxel®+ an Optically Stimulated Luminescence Detector (OSL) based on aluminium oxide (Al_2O_3:C) manufactured by Laundauer® Inc. (Glenwood, IL). OSL type used in this study was Luxel®+ 'Ta': Which reads Photon (X or gamma rays), beta, fast/thermal/intermediate neutrons. After exposure, the detectors were sent back to the manufacturer for reading [7]. The luminescence quantified during analysis was applied to a dose algorithm that depends on the response ratios which separates different filter positions within the dosimeter to discriminate between beta and photon (X and gamma) radiation fields to control exposure results [7].

D. *Neutron Detectors*

Neutron was accurately measured using Neutrack®, a track-etch detector, which was part of Luxel®+ 'Ta' dosimeter. The Neutrack® detector was a CR-39 (allyl diglycol carbonate) based, solid-state nuclear track detector that measures exposure due to neutrons. Neutrack®'s thermal/intermediate neutron dosimeter, which is used in this study, has a design intended for fast, intermediate and thermal neutrons. The left region of the chip uses a polyethylene radiator for fast neutrons while the right area uses boron loaded Teflon® radiator for fast, intermediate and thermal neutrons that record alpha particles resulting from neutron interactions in the dosimeter.

E. *Radiation Dose Report and Dosimetry – Laundauer® Inc.*

1) *Dose Determination Algorithm - Formulism (X-Ray or Electron Beam)*

The response of an OSL dosimeter is quasi-linear with a dose value for any energy. A small departure from linearity is corrected together with loss of signal from the difference in time between irradiation and reading as well as corrections for energy/block and position of the OSL in the beam. The sensitivity of a dosimeter is defined as the ratio of dose to signal [8].

$$Sensitivity\ (S) = \frac{Dose}{Signal}$$

$$Dose = S \text{ x } Signal$$

$$Dose = S \text{ x } Signal \text{ x } ECF \text{ x } DCF \text{ x } K_L \text{ x } K_F \text{ x } K_E$$

ECF = Element Correction Factor
DCF = Depletion Correction Factor
K_L = Supra linearity correction
K_F = Fading correction
K_E = Energy/block correction

2) *Dose Determination (Neutrons) – Track Etch Technology*

The principle of dose determination was based on the counting of the number tracks etched into the surface of a CR-39 detector after irradiation. These tracks are caused by, either recoil protons produced by the interaction of neutrons with the hydrogen atoms contained in a polyethylene radiator (fast neutron), or alternatively alpha particles produced from the 10B (n, α)7 Li reaction in boron loaded radiator (thermal neutrons). Following irradiation, the material is etched in a bath of sodium hydroxide, for approximately 15 hours at 70°C, to enlarge the proton recoil or alpha tracks.

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The dose is then evaluated by counting the number of tracks.

III. RESULTS

Photon head-leakage measurements:

Percentage leakage value was calculated from the dose value (mrem) using the formula given below.

[% leakage = Dose (rem)/MU]. 10,000MU was used for Energy 10MV FFF. Photon dose equivalent value for measurement location 'A' was 217 mrem.

E.g. 10MV FFF for location 'A' % leakage = (217 x 0.001/10,000) = 0.00217%.

Vendor provided data for Out-Beam in patient plane photon head-leakage is available only for high energies starting from 10MV. The measured values are slightly higher compared to the vendor provided data. Values for 10MV FFF is very less compared to other higher energies.

F. *Neutron head-leakage measurements:*

The neutron head-leakage value is significant only after energy 10MV. **Table 2** shows the in-beam average percentage neutron head-leakage values at isocenter for different energies for field sizes (0.5x0.5) cm^2 and (10x10) cm^2.

Table 2: In-Beam at isocenter Neutron head-leakage (%)

Mode	**10MV**	**10MV FFF**	**18MV**	**20MV**	**22MeV**
0.5x0.5 cm^2	0.0020	0.00035	0.0253	0.0286	0.0008
10x10 cm^2	0.0032	0.0010	0.0505	0.0627	0.0020

It clearly shows that maximum measurement values are for 20MV beam followed by the 18MV beam. The least values are found for 10MV FFF beam. The measurement values for the highest energy of the electron beam in the machine (22MeV) was also comparatively very low. The measured and vendor provided data for Out-Beam neutron head-leakage value is measured with the patient plane at 23 locations. The measured values are higher than the vendor-provided data. However, the trend of curves roughly matches with each other. Values for 10MV and 10MV FFF are very less compared to 18MV and 20MV beams.

IV. DISCUSSION

The maximum and average limits (in percentage) specified by IEC -60601-2-1 in section 201.10.1.2.102.3 for Out-Beam measurements both for photon head leakage and neutrons in the patient plane are 0.2, 0.1 and 0.05, 0.02 respectively. For photons, extensive measurements were made at 23 locations for leakage radiation for Out-Beam in the patient plane. Extensive measurements were made for neutron-head leakage radiation for In-Beam at isocenter and Out-Beam in the patient plane. Head-leakage values for all the energies understudy are within the limit. It was clear that for Flattening Filter Free (FFF) beams, the removal of the flattening filter results in the decrease in photon head leakage. While comparing the measured values with vendor provided data, a difference in agreement as low as 9.5% (18MV) to as high as 13.2% (10MV) (**Error! Reference source not found.** [C]) is observed. So, for photons, the average difference in head-leakage dose estimation was found to be ~ 11.3, for the electron beam percentage deviation was found to be 25%.

The trend of the measurements curve was roughly matching with the vendor provided data for higher energies, starting with 10MV.

An asymmetry in the gun/target direction, is observed. For neutrons, two sets of measurements are taken: In-Beam at isocenter for field size 10x10cm^2 and jaws completely closed (0.5x0.5cm^2) and Out-Beam in the patient plane at 23 locations. Measurement values for In-Beam at isocenter shows that the maximum neutron leakage was generated by 20MV, and the minimum value was generated by 10MV FFF (**Table 2**). The value for the highest electron energy (22MeV) was also very less compared to 18MV and 20MV photons.

For In-Beam at isocenter, while comparing the measured values with vendor provided data, it is observed that the same trend and a difference in agreement as low as 7.3% (20MV, 0.5x0.5cm^2), 1.9% (18MV, 10x10cm^2) to as high as 50% (10MV, for both field sizes. So, the average difference in neutron head-leakage dose estimation was found to be ~ 19.7% for field size 0.5x0.5cm^2 and 22.4% for field size 10x10cm^2.

For Out-Beam in the patient plane for 23 locations, the maximum value for neutron head-leakage was recorded for the 20MV beam (0.0276%), and the minimum value was recorded for 10MV FFF beam (0.0003%). The highest average value was also recorded for the 20MV beam (0.0184%), and the lowest average value was for 10MV FFF beam (0.0001%). While comparing the measured values with vendor provided data for Out-Beam neutron head-leakage, a difference in agreement as low as 25.23% (10MV) to as high as 32.3% (10FFF) were observed. So, the average difference in neutron head-leakage dose estimation was found to be ~ 27.9%.

The comparison was made between TrueBeam® measured head leakage data with the Clinac. It was observed that the photon head leakage value for Clinac was higher, and the neutron head-leakage value was found to be slightly less than the TrueBeam® values.

V. CONCLUSION

The photon and neutron head-leakage values In-Beam at the isocenter and Out-Beam in the patient plane (23 points outside area M) were measured for high energy photons, 10MV, 10MV FFF, 18MV and 20 MV, and the maximum value of electron energy, 22MeV, for a Varian TrueBeam® linac. The average photon and neutron head-leakage value were less than the regulatory limit. The comparison was made between both photon and neutron components of the measured head-leakage values with the manufacturer provided results and a reasonably good agreement was found. This study indicates that there was a higher dose due to head-leakage contribution from neutrons once move towards 20MV range of photon energy. The comparison was made between TrueBeam® measured head-leakage data with the Clinac. It was observed that the photon head leakage value for Clinac was higher, which indicates that the TrueBeam® head is a better design as far as photon-head leakage value is concerned. The Clinac neutron head-leakage value was found to more or less same to be that of TrueBeam® values.

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