Measurement of Neutron Leakage and Facility Survey of a Newly Commissioned Quadruple Photon Energy Medical Linear Accelerator Using a Neutron Survey Meter

Avin Kumar[1], A. S. Karunya[2], K. R. Nisha[3], Sanjay Kumar[4], Sruthi Sreenivasan[5]

[1]Cheif Medical Physicist and Radiation Safety Officer, Department of Radiation Oncology, A.J Hospital and Research Centre, Mangaluru- 575004, India
**Corresponding Author Email: avinkumarb[at]gmail.com*

[2]Medical Physics Intern, Department of Radiation Oncology, A.J Hospital and Research Centre, Mangaluru- 575004, India
Email: *karunya7760[at]gmail.com*

[3]Medical Physics Intern, Department of Radiation Oncology, A.J Hospital and Research Centre, Mangaluru - 575004, India
Email: *nishakr259[at]gmail.com*

[4]Medical Physics Intern, Department of Radiation OncologyA.J Hospital and Research Centre, Mangaluru - 575004, India
Email: *sanjuwsanjay[at]gmail.com*

[5]Medical Physicist, Department of Radiation Oncology, A.J Hospital and Research Centre, Mangaluru- 575004, India
Email: *sruthi.ssiv[at]gmail.com*

Abstract: ***Neutron head leakage and survey measurements at clinical Linear Accelerators (LINAC) for Radiotherapy are aimed at protecting patients, radiation workers, hospital staff, and even the general public. The purpose of this study was to measure neutrons produced via the (γ, n) reaction in the LINAC head for a 15 MV X-ray beam. A functional electron linear accelerator with energy 15 MV was used to measure the neutron leakage along the patient plane and other than the patient plane using a commercially available neutron survey meter (Model 30-7). LINAC collimator was kept in the fully closed position while irradiating radiation and the measurements were taken at various positions. For the facility survey, multiple locations were identified to analyze the neutron existence. Entire measurements were carried out in a dose rate mode and analyzed concerning the maximum allowed tolerance. The survey was carried out using a neutron survey meter. Head leakage along the patient plane at various positions i.e., 1m and 2m from the isocenter, similarly other than the patient plane i.e., 1m at the lateral sides of the LINAC head were analyzed. The maximum & average leakage along the patient plane were 0.005% & 0.0049% and leakage other than the patient plane was 0.0049% & 0.0048% respectively. Survey readings across the facility were below the radiation exposure rate limit set by the regulatory board i.e., less than 10μSv/hr. Institutions which are having LINAC with a photon energy of more than 10MV must carry out the neutron head leakage test and room survey periodically as per the regulatory board and ensure that no excess amount of leakage is evidenced in and around the facility. This study confirmed that there is no harmful neutron leakage at the site and also allows the institute to continue using a 15MV beam and get good clinical outcomes with deep-seated cancer tumors.***

Keywords: Linear Accelerator, Neutron Survey Meter, Neutron head leakage, Room Survey

1. Introduction

Medical linear accelerators are the most frequently applied radiation therapy machines in the locoregional treatment of cancers by producing either high-energy electron or photon beams. However, with high-energy photons (>10 MV), the interaction of these photons with different high-Z nuclei of materials in components of the LINAC head unavoidably generates neutrons [1]. Neutrons are generated in the accelerator head (target, collimators, flattening filter, and shields), treatment room, and directly in the patient's body. However, since cross sections for high Z materials are around 50 times higher than for low Z, photoneutron production is mainly due to (γ, n) reactions in the accelerator head [2],[3]. Moreover, the high Z materials present in the accelerator head have low neutron absorption cross-sections for the generated neutron energies. Therefore, neutrons are not shielded by the LINAC collimators and reach the patient, contributing an extra dose not taken into account in radiotherapy treatments [4]. It is difficult to measure photoneutron dose inside the treatment field due to very intense gamma irradiation.

Concerning radiation protection, the AAPM recommends that the radiation survey is mandatory for a new facility or old installation that has been modified, to ensure that the maximum exposure limits in the adjacent areas do not exceed from the permissible limit [5]. Radiation monitoring is carried out: to assess workplace conditions and individual exposures, to ensure acceptably safe and satisfactory radiological conditions in the workplace, and to keep records of monitoring over a long period, for regulation or good practice [6]. Neutron survey meters operate in the proportional region so that the photon background can be easily discriminated against [7].

2. Materials and Methods

The LINAC used under this investigation is Elekta Synergy Platform located in A J Hospital and Research Centre, Mangalore, Karnataka. The particular LINAC offers four photon energies namely 4MV, 6MV, 6MVFFF &15MV and five electron energies, 6MeV, 8MeV, 10MeV, 12MeV & 15MeV. The LINAC was operated in flattening filter (FF) mode for the 15 MV beam with the jaws and multi-leaf collimators in the fully closed position [8].

A neutron survey meter (Model 30-7) was used for the measurement of neutron dose rate at the LINAC treatment room (Fig.1). The neutron survey meter consists of a 3He proportional counter tube. It has a lower boron concentration and offers greater sensitivity, typically 10 CPM per µSv/h (100 CPM per mrem/hr), but tends to over-respond in the 5 keV range [7]. A neutron survey meter was placed on the treatment couch for irradiation. The leakage data of LINAC were taken as a function of delivered dose, and detector position [8].

2.1 Neutron Head Leakage

For the whole experiment, the Source to Surface Distance (SSD) was kept at 100 cm. The gantry, collimator, and couch were kept at an angle of zero degrees. The dose rate considered for the study was 600MU/min at the isocenter along the central axis. To obtain the live time data, the survey meter was observed by a video recording device kept facing the detector. The positions of the detector were taken concerning the isocenter (0,0,0). The survey meter was exposed at 1m & 2m distances from the central axis with different couch angles 0^0, 30^0, 60^0, 90^0, -30^0, -60^0, and -90^0 (Fig 2), which is considered as the leakage measurement along the patient plane.

In the neutron survey meter dose rate mode was selected, so that the percentage neutron leakage concerning the central axis can be analyzed using the equation (1) which states that the percentage neutron leakage (N_L) at various positions along the patient plane and other than the patient plane is the ratio of the dose rate measured at different positions ($D_{P)}$ to the dose rate at nominal treatment distance (D_{NTD}).

$$N_L = [D_P / D_{NTD}] *100 \quad (1)$$

Figure 1: Neutron Survey Meter (Model 30-7)

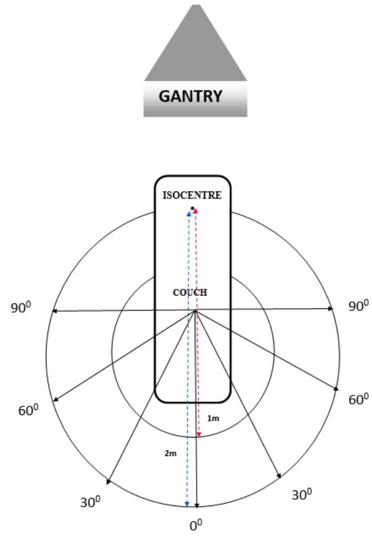

Figure 2: Measurement setup for neutron leakage test.

2.2 Neutron Leakage Along Gun – Target

The LINAC was operated for a dose of 100 cGy with 15MV energy by keeping a gantry angle of 180^0. The detector was placed at various positions along the gun to target direction as shown in Fig.3. The data were captured by a video recording system kept near the detector inside the treatment room.

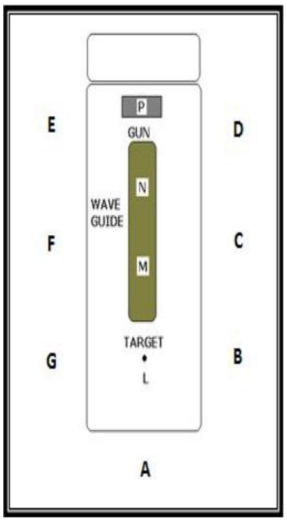

Figure 3: Measurement setup for neutron leakage test along gun–target direction

2.3 Neutron Room Survey

However, for a primary laminated barrier in addition to neutron leakage, neutrons are also produced by the interaction of the primary photon beams with the lead shielding in the primary barrier. Lead is not very effective in shielding neutrons, but only reduces the neutron energy. Thus, a neutron survey is must be performed outside the primary barrier since it laminated.

Set the LINAC with energy 15MV, field size, and dose rate of $5×5cm^2$ and 600 MU/min respectively. The survey was performed at different locations as shown in Fig.4.

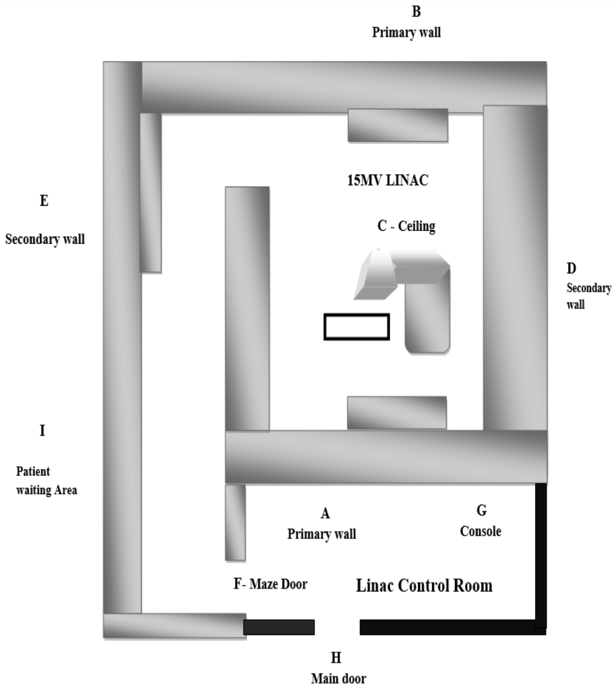

Figure 4: Linear Accelerator Vault Design

3. Results and Discussion

3.1 Neutron Leakage Along Patient Plane

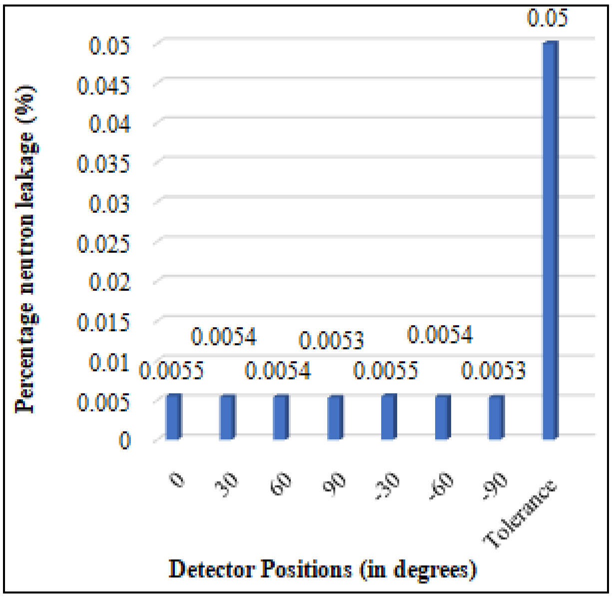

Figure 5: Neutron dose rate at 1m distance

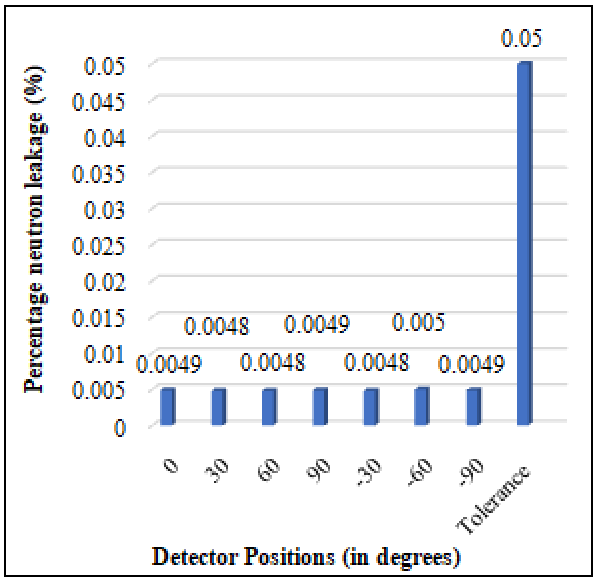

Figure 6: Neutron dose rate at 2m distance

3.2 Neutron Leakage: Gun-Target (Other Than Patient Plane)

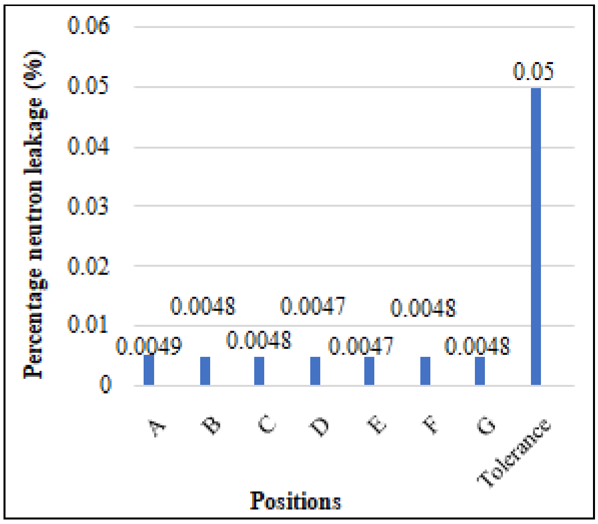

Figure 7: Neutron dose rate along gun-target

3.3 Neutron Room Survey

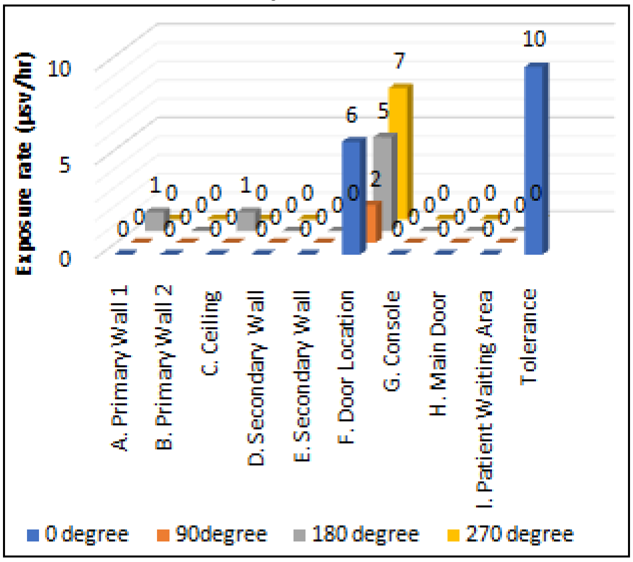

Figure 8: Neutron room survey data

The result of this study has provided information about the percentage of neutron leakage radiation through the treatment head & room survey of the LINAC (Elekta Synergy Platform) facility. According to the International Electro-Technical Commission (IEC) 60601-2-1 international standard, for neutrons, the head-leakage limit for out-beam in the patient plane are maximum of 0.05% and an average of 0.02% [16]. In this study, head leakage along the patient plane at 1m and 2m distance from the isocenter was found to be a maximum of 0.005% and an average dose of 0.0049%. Measurements on the floor (other than the patient plane) at a 1m distance, showed the result of a maximum dose of 0.0049% and an average of 0.0048%, which is within the tolerance limit i.e., 0.05%. The study also performed a survey for the neutron, which was found to be below regulatory limits for all survey locations. The current study provides valuable data for neutron distribution within the treatment room, which is important in improving patient safety through protective measures.

Conclusion

The study was concerned with measuring the neutron dose rate of the Elekta Synergy Platform, operating at 15 MV potential. Institutions with LINAC more than 10MV must carry out the neutron head leakage test as stipulated by the competent authority and ensure that no excess amount of leakage is evidenced in the facility. Also, the neutron dose equivalent rate in the LINAC treatment room is essential in informing matters concerning the adequacy of shielding, in improving patient protection, and in seeking to mitigate the risk of secondary cancer.

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Author Profile

Mr. Avin Kumar, Completed his Masters in Medical Physics from Manipal University. Presently working as Chief Medical Physicist and Radiation Safety Officer at A.J Hospital and Research Centre, Mangaluru, Karnataka, India

Mrs. Karunya A S., Completed her Masters in Medical Physics from Mangalore University. Presently doing internship in Medical Physics at A.J Hospital and Research Centre, Mangaluru, Karnataka, India.

Mrs. Nisha K. R., Completed her Masters in Medical Physics from Mangalore University. Presently doing internship in Medical Physics at A.J Hospital and Research Centre, Mangaluru, Karnataka, India.

Mr. Sanjay Kumar, Completed his Masters in Medical Physics from Mangalore University. Presently doing internship in Medical Physics at A.J Hospital and Research Centre, Mangaluru, Karnataka, India.

Mrs. Sruthi Sreenivasan, Completed her PG Diploma in Medical and Radiological Sciences from Amrita Institute of Medical Sciences, Kochi. Presently working as a Medical Physicist at A.J Hospital and Research Centre, Mangaluru, Karnataka, India.