Measurement of photoneutron flux at the medical LINAC by activation analysis

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Introduction

Radiotherapy treatment using photon beams are widely used to treat cancer tumors using medical linear accelerators (LINAC). The typical photon energies used for the treatment range from 6 to 20 MeV. The bremsstrahlung photons are generated when energetic electron beam is incident on the high Z target. During operation of the medical LINAC, the photons interact with the components of the LINAC such as target, flattening filter, primary and multileaf collimators and other materials in the accelerator head. These giant dipole resonance (GDR) interactions of photons with high Z materials produce unwanted photo neutrons. The GDR interactions of photons are dominant in the photon energy range of 8 MeV to 20 MeV. The energy spectrum of these photoneutrons is complex, which has around 15 % thermal neutrons (0.01-0.5 eV) and 15 % epithermal neutrons (0.5 eV- 5keV) and intermediate to fast neutrons (5 keV to 10 MeV) around 70 %. The photo neutron contamination becomes quite significant for around 10 to 20 MeV photon beams. The knowledge of photo neutrons flux is required for calculation of ambient dose received by the patients. These neutrons are also a problem for the operators in control room if the shielding is not adequate.

In the present work, we have measured the photo neutron flux at the patient table using activation of ^{197}Au, ^{115}In and ^{55}Mn isotopes. The photo neutrons are captured by the target atoms inducing (n,γ) reactions.

Experimental Details

The samples consisted 0.5 gm of pure Au foil and 1 gm of In_2O_3 and MnO_2 (99.99%) in powdered form having natural isotopic abundance. The irradiations were performed using a medical LINAC at Dr. Vikhe Patil Memorial Hospital, Ahmednagar, India. The linear accelerator provided 10 and 15 MeV bremsstrahlung photons for irradiations. The gantry of the accelerator was pointing downwards and the collimators (jaws) were opened to give a field size of 10 x 10 cm at the patient table situated at 100 cm from the bremsstrahlung target. The samples were placed in the given field size and irradiated with 10 MeV and 15 MeV bremsstrahlung photons for a period of 1500 s. A constant dose rate of 570 ± 10 and 650 ± 10 cGy/min was recorded for 10 MeV and 15 MeV energies respectively. The irradiations were performed for 1800 sec. After the irradiation samples were transferred to the control panel room for offline gamma ray spectrometry. The gamma spectroscopy was performed with a 30% HPGe detector, which was precalibrated with a ^{152}Eu point γ source.

Data Analysis

The measured gamma spectra were analyzed for the capture reactions mentioned in Table. 1. The photo peaks 411.8 (95.62%) keV of ^{198}Au, 1293.56 (84.8%) keV of ^{116m}In and 846.76 (98.85%) keV ^{56}Mn were used for the calculations.

Table 1 Nuclear spectroscopic data for the capture reactions.

Sr. No.	**Reaction**	**Half Life**	**Gamma Peak (keV)**
1.	^{197}Au(n,γ)^{198}Au	2.69 d	411.8 (95.62%)
2.	^{115}In(n,γ)^{116}In	54.29 m	1293.56 (84.8%)
3.	^{55}Mn(n,γ)^{56}Mn	2.57 h	846.76 (98.85%)

The photoneutron flux incident on the samples can be estimated by the eq. 1.

$$<\phi_s>=\frac{FA\lambda}{<\sigma_s>\varepsilon I_\gamma N(1-e^{-\lambda t_1})(e^{-\lambda t_2})(1-e^{-\lambda t_3})} \quad (1)$$

Where, F is the activity correction factor for self-absorption and true coincidence summing, A is the area under the gamma peak, λ is the decay constant, ε is the detector efficiency, Iγ is the gamma peak intensity, N is the number of target atoms, t_1 is the irradiation time, t_2 is the time between the stop of irradiation and start of the gamma counting, t_3 is the counting time and $<\sigma_s>$ is the flux weighted average cross section of capture reactions determined by eq. 2.

$$< \sigma_s > = \frac{\Sigma \sigma \phi}{\Sigma \phi} \quad (2)$$

where ϕ is the Geant4 simulated photon neutron energy spectrum and σ is the cross section of the reaction at the corresponding photon energies calculated with TALYS 1.95 [1].

The photon neutron energy spectrum was simulated by adopting the accurate geometry of the medical LINAC in the Geant4 [2] code. The Geant4 code can effectively transport electrons, gamma and neutrons through matter employing electromagnetic interaction physics in low and high energy range. The Geant4 simulations were performed by using the QGSP_BIC_HP physicsList which uses the binary cascade model from high precision neutron package (NeutronHP) for the transport of neutrons below 20MeV to thermal energies. The low energy neutron physics data is taken from the G4NDL cross-section library. The simulated photon neutron energy spectrum is shown in Fig. 1.

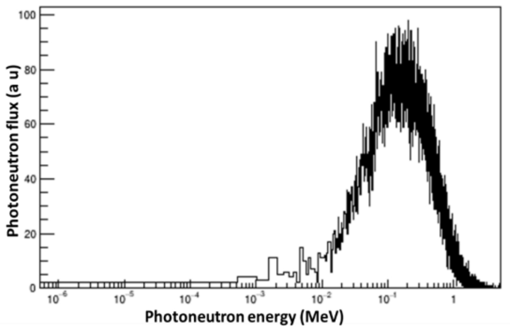

Fig 1: A typical Geant4 simulated photoneutrons energy spectrum for the medical LINAC operated in 15 MV photon mode.

Results

The measured photo neutron flux is presented in the Table 2. The photo neutrons flux is of the order of ~10^4 neutrons/cm^2.s for the medical LINAC in 15 MV photon mode and ~10^3 neutrons/cm^2.s in 10 MV photon mode. The results are in good agreement with the data of the authors Vysakh et al. [4] and Vagena et al. [3] The data can also be used to determine the photoneutron energy spectrum by unfolding techniques.

Table 2 Estimated photo neutron flux at the patient table of the medical LINAC

Reaction	**Photo neutron flux (n/cm^2.s)**	
	10 MeV	**15 MeV**
^{197}Au(n,γ)^{198}Au	6.682 x 10^3	7.207 x 10^4
^{115}In(n,γ)^{116}In	2.28 x 10^3	4.923 x 10^4
^{55}Mn(n,γ)^{56}Mn	4.321 x 10^3	9.677 x 10^4

Conclusion:

The energy spectrum of the photoneutrons has been simulated by Geant4 Monte Carlo code by taking into account the accurate geometry of the Medical LINAC. The major portion of the photoneutron energy lies in the intermediate to fast energy range. The photoneutrons flux has been estimated by activation of Au, In and Mn samples. The calculated results are important for the estimation of ambient dose or out of field dose to patient. The results are also significant for designing of medical LINAC facility and neutron contamination estimation. Similar measurements and simulations can be performed for other designs of linear accelerators operated at various electron energies. The methodology presented here can prove helpful for future experiments in mixed field areas for estimation of low energy neutron flux.

References

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