

MONTE CARLO SIMULATION AND EXPERIMENTAL EVALUATION OF PHOTONEUTRON SPECTRA PRODUCED IN MEDICAL LINEAR ACCELERATORS

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Abstract

Linear accelerators for the cancer radiotherapy generally make use of high-energy photon beam. If the photon energy is greater than 6-7 MeV, neutrons are generated by photonuclear reaction in the accelerator head. The neutron spectrum and yield at the patient plane must be known in order to optimize the treatment and limit secondary malignancies. The spectrum of neutrons generated by (γ,n) reaction in the SL20I ELEKTA multileaf accelerator has been obtained at the patient plane with a Monte Carlo simulation. The calculated spectrum has been checked out against experimental measurements performed, in different positions at the patient plane, with a passive bubble spectrometer.

1 INTRODUCTION

The reevaluation of the biological risk from neutron radiation has improved the importance of a reliable neutron dosimetry. There is an urgent request from medical physicist of an accurate estimation of the undesired neutron dose associated with the photon beams produced in the linear accelerator commonly used in the cancer therapy. The knowledge of the photon and neutron spectrum at the patient plane allows a more accurate evaluation of the total dose.

Measurements of such spectra are difficult, due to the high fluence rate of photon to respect to neutrons and the pulsed radiation field, which can produce saturation and noise problems in the electronic equipment. In this work the linear accelerator SL20I-ELEKTA [1], equipped with the multileaf collimation system (MLC) has been simulated with the new Monte Carlo code MCNP-GN, especially developed to treat the photoneutron production in medical linear accelerators. The neutron fluence, as a function of the neutron energy, has been calculated in different positions at the patient plane; the corresponding dose equivalent has been evaluated by using the ICRP74 [6] conversion factors.

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The Monte Carlo results have been compared with the experimental spectra, measured with the passive bubble spectrometer BDS [4] at the Hospital of «La Fe» (Valencia, Spain) where a SL20I accelerator is installed. The BDS spectrometer system has been chosen because the passive characteristics and the photon insensitivity allow to overcome the experimental difficulties previously described. This Monte Carlo approach associated with the BDS spectrometer represents a new and complete tool to describe the neutron field.

2 SL20I ELEKTA MULTILEAF (MLC) ACCELERATOR

The fundamental requirement for a radiotherapy treatment

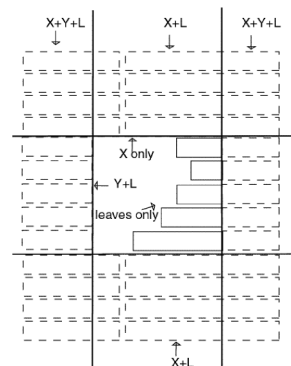


Figure 1: Irregular field profile with MLC.

is the delimitation of the irradiated region as close to the tumor volume as possible, minimizing the dose to the surrounding healthy tissues. With this aim, the most modern machines are equipped with the multileaf system: a set of movable leaves is applied to define the field size and shape. The ELEKTA SL20I accelerator uses a set of 80 lead+tungsten leaves, which define the treatment field in the Y direction; leaves are stepped to create an overlap and limit the leakage. Further collimation is provided by traditional X and Y shielding, to reduce the photon leakage between the leaves to acceptable levels (figure 1, table 1).

Table 1: SL20I characteristics.

Max photon energy	18 MeV
Target	Tungsten
Primary collimator Top	Tungsten
Flattening filter	Iron
Leaves	Tungsten+Lead
Y back-up collimator	Tungsten
X collimator	Tungsten+Lead

2 MONTE CARLO SIMULATION WITH MCNP-GN

The Monte Carlo code MCNP-GN has been especially developed to study the neutron leakage in medical LINACS used in the photon cancer radiotherapy. The physical routines of the Monte Carlo code GAMMAN [2] have been introduced in the Monte Carlo code MCNP4B [7]. The Monte Carlo code MCNP-GN evaluates the neutron production in high atomic number materials

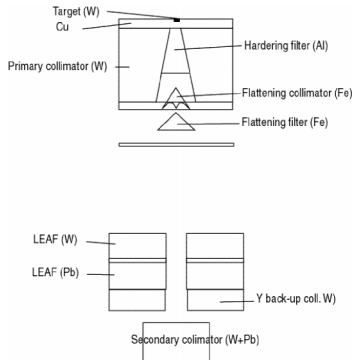


Figure 2: Geometrical model of SL20I MLC simulated with MCNP-GN.

through (γ, n) reaction in the energy region of the giant resonance ($E < 30$ MeV). These characteristics, together with the capability to model complex geometries, make MCNP-GN especially useful for medical linear accelerator simulations. In fact, by use of an unique code, it is possible to obtain both the photon and the photoneutron spectra produced in the accelerator field. The realistic geometrical model of ELEKTA SL20I MLC (in the high power configuration) has been simulated to obtain a 10×10 cm² treatment field, irradiated with 1 Gy photon dose at the patient plane (figure 2).

3 THE BDS SPECTROMETER

The passive neutron spectrometer BDS [3] has been used to obtain neutron spectra in term of fluence as a function of neutron energy. The consists of a set of bubble dosimeters, characterized by 6 different energy thresholds of detection; the total energy range extends from 10 keV to 20 MeV. Each detector includes a polycarbonate vial filled with elastic tissue-equivalent polymer; superheated freon drops are dispersed inside the gel. The interaction between incident neutrons and polymer causes a proton emission; the consequent energy deposition generates the bubble forming, due to the metastable state of freon. The number of bubbles trapped in the polymer, proportional to the neutron fluence, is recorded. The neutron spectrum is then is obtained by processing the experimental data with the unfolding code BUNTO [4]. Due to the characteristics of passivity and insensitivity to photons, this

spectrometric system can be used in mixed neutron and photon fields, as the treatment room. Neutron spectral measurements can be therefore performed also in positions corresponding to the treatment area, unlike several other devices, commonly used for neutron dosimetry and radioprotection.

4 EXPERIMENTAL MEASUREMENTS WITH BDS SPECTROMETER

Spectral and integral measurements of neutron fluence and dose equivalent have been performed at various positions (figure 3) in the irradiation room of linear accelerator SL20I-ELEKTA, installed in the hospital «La Fe», Valencia (Spain). The measurements have been realized in the following conditions:

- 100 MU/Gy
- 10×10 cm² photon field at the isocenter
- 100 cm SSD (Source Surface Distance)

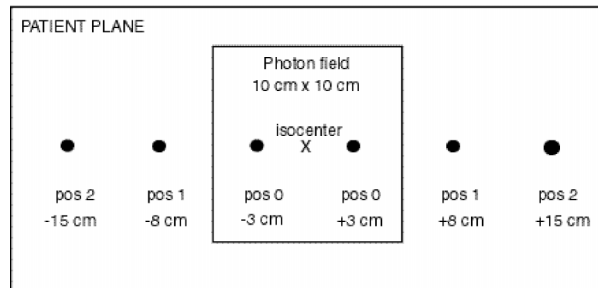


Figure 3: Measurement positions at the patient plane, SDD=100 cm.

5 COMPARISON BETWEEN SIMULATION AND MEASUREMENTS

In figures 4 and 5 the neutron experimental spectra evaluated at the patient plane, per 1 Gy photon absorbed dose (SSD=100 cm) are presented. The neutron spectra calculated by the Monte Carlo code MCNP-GN in the same positions are also shown. The comparison is very satisfactory; in fact the simulated spectra are uniquely normalized to the number of electrons giving 1 Gy photon dose at the isocenter. The spectral neutron dose equivalent (ICRP60 [5], [6]) (per 1 Gy photon dose at the patient plane) was also obtained from the experimental spectra at the different positions to respect to the beam axis. In figure 6 the neutron integral dose equivalent and the photon absorbed dose calculated with MCNP-GN at different positions are shown together.

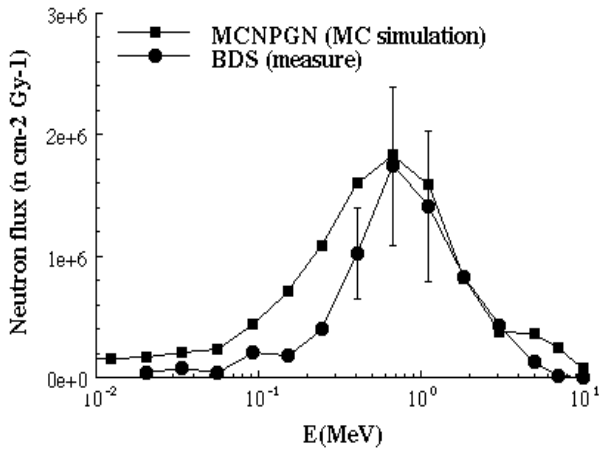


Figure 4: Comparison between experimental and simulated spectrum. Position pos1 – 8 cm from isocenter.

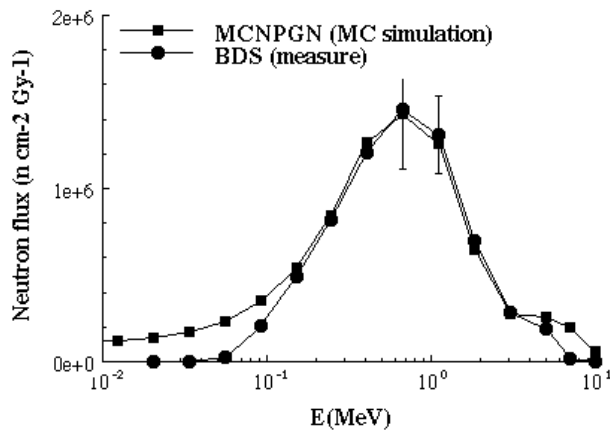


Figure 5: Comparison between experimental and simulated spectrum. Position pos2 – 15 cm from isocenter.

Table 2: Integral neutron fluence and neutron dose equivalent evaluated from spectral data at various positions.

		Integral neutron fluence per 1 Gy photon dose - cm ⁻² Gy ⁻¹		integral neutron dose equivalent per 1 Gy photon dose (ICRP 60) - mSv Gy ⁻¹	
		10 keV-20 MeV	300 keV-20 MeV	10 keV-20 MeV	300 keV-20 MeV
POS0	MCNP-GN (simulation)	1.87 x 10 ⁷	9.83 x 10 ⁶	4.99	4.37
	BDS (experiment)	(2.06 ± 0.31) 10 ⁷	(9.62 ± 1.44) 10 ⁶	5.01 ± 0.75	4.60 ± 0.69
POS1	MCNP-GN (simulation)	9.86 x 10 ⁶	6.88 x 10 ⁶	3.53	3.04
	BDS (experiment)	(7.11 ± 1.64) 10 ⁶	(5.57 ± 1.28) 10 ⁶	2.66 ± 0.61	2.48 ± 0.57
POS2	MCNP-GN (simulation)	7.79 x 10 ⁶	5.39 x 10 ⁶	2.76	2.38
	BDS (experiment)	(7.60 ± 1.98) 10 ⁶	(5.18 ± 1.35) 10 ⁶	2.62 ± 0.68	2.28 ± 0.59

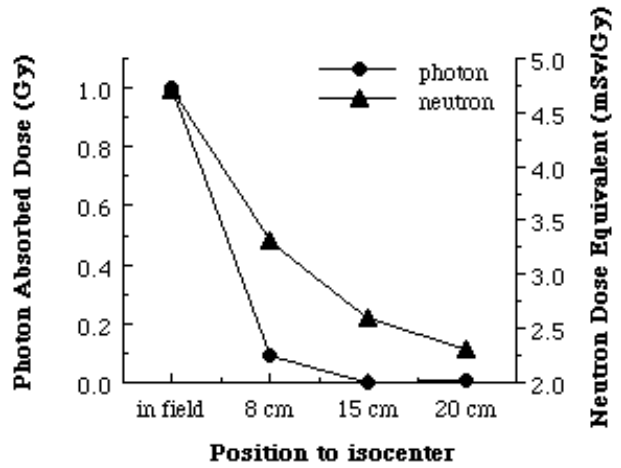


Figure 6: Integral photon absorbed dose and neutron dose equivalent calculated with MCNP-GN at the various positions with respect to the isocenter.

6 CONCLUSIONS

From these results it is pointed out that the neutron dose equivalent in a typical treatment is not negligible. In fact the neutron dose equivalent remains greater than 2 mSv/Gy also in far positions from the treatment field. Therefore, this new system, consisting of Monte Carlo simulation and spectral measurements, represents a reliable approach to evaluate the leakage neutron field and to optimize the treatment plan.

7 REFERENCES

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