Neutron spectra and H*(10) of photoneutrons inside the vault room of an 18 MV LINAC

A. Bañuelos-Frías, C.G. Borja-Hernández, K.A. Guzmán-García, C. Valero-Luna, V.M. Hernández-Dávila, and
H.R. Vega-Carrillo.
Unidad Académica de Estudios Nucleares,
Universidad Autónoma de Zacatecas,
C. Ciprés 10, Fracc. La Peñuela, 98068 Zacatecas, Zac.
lanb535@yahoo.com

Neutron spectra and the ambient dose equivalent were estimated inside the radiotherapy hall with an 18 MV linac. Estimations were carried out using Monte Carlo methods where a realist hall was modeled including a phantom made of equivalent tissue. The source term for photoneutrons was calculated using the Tosi *et al.* function that account for evaporation and knock-on neutrons. The spectra were estimated using two different energy distributions. Detectors were located in several sites inside the hall including the maze and outside the hall door, all detectors were located at the plane were the isocenter is located. In the treatment hall, as the distance respect to the isocenter is increased, the amount of neutrons and the H*(10) are reduced, neutrons in the high-energy region are shifted to lower region peaking around 0.1 MeV, however the epithermal and thermal neutrons remain constant due to the room-return effect. In the maze the spectra are dominated by epithermal and thermal neutrons that contributes to produce activation and the production of prompt gamma-rays.

Keywords: Monte Carlo simulations; Linac; Radiotherapy; Spectrometry.

El espectro de neutrones y el equivalente de dosis ambiental fueron estimados dentro de una sala de radioterapia con un Linac de 18 MV. Las estimaciones se llevaron a cabo utilizando métodos Monte Carlo donde una sala realista fue modelada incluyendo un fantoma de tejido equivalente. El término fuente para neutrones fue calculado usando la función de Tosi *et al*, la cual contabiliza los neutrones de evaporación y reacción directa. El espectro fue estimado usando dos diferentes distribuciones de energía. Los detectores fueron colocados en el plano donde se encuentra el isocentro. Dentro de la sala de tratamiento, como la distancia respecto al isocentro aumenta, la cantidad de neutrones y H*(10) se reduce, los neutrones dentro de la región de alta energía son desplazados a una región de menor energía de alrededor de 0.1 MeV. Sin embargo, los neutrones epitérmicos y térmicos permanecen constantes debido al efecto de room-return. En el laberinto el espectro es dominado peor neutrones térmicos y epitérmicos los cuales contribuyen a la producción de activación y a la producción de rayos gamma prontos.

Descriptores: Simulaciones Monte Carlo; Linac; Radioterapia; Espectrometría

PACS: 24.10.Lx; 87.56.bd; 87.57.uq; 29.30.Hs

1. Introduction

Radiotherapy using high energy linear particle accelerators or linacs to irradiate cancerous tissues with monoenergetic electrons or bremsstrahlung photons is one of the most effective treatments to fight this illness. The most of that devices that operates under energetic potentials over 10 MV, are capable to produce neutrons trough photonuclear and electronuclear reactions due to the interactions of the photons or electron respectively with the heavy materials contented in the head of the linac and all along the beam way. The average binding energy per nucleon of the material conforming the linac head are around the 8 MeV [1-3].

The energetic distribution of those primary neutrons, also named spectrum, originated by the gamma-neutron reaction has two main components: one 0.2 to 2 MeV peak due to the nuclear evaporation process and a high energy neutron tail due to direct reaction or knock-on peaked around 1 to 2 MeV [4].

Neutron parasite radiation is approximately isotropic and is transmitted at any direction from the beam, the shielding, the collimator in the linac's head and also heading to additional interactions with the walls, the floor, the ceiling, medical equipment and even the patient undergoing the medical treatment. The production of photoneutrons using high energy Linacs is a radiation protection issue, consequently that's the reason of the whole body exposition due to neutron radiation inside the treatment room and the subsequent induced radiation represent a potential hazard for the patient and also for the staff working in the Linac room, [1, 3, 5] due to the neutrons spectra peaks ranging between the 0.1 MeV to 1.0 MeV, has a very high damage effectiveness to damage tissues whose weighting factor is 20 [5].

The objective of this work is to calculate the neutron spectra and the ambient equivalent dose H*(10) due to the neutron radiation inside the treatment hall with an 18 MV LINAC using Monte Carlo method.

2. Materials and Methods

Neutron spectra and ambient dose equivalent were estimated using the MCNP5 code [6]. In the calculation a generic ra-

diotherapy room, $13.2 \times 11.8 \times 3.9$ m^3, the room's walls were modeled with 2.35 g/cm^3 National Bureau of Standard concrete. The two primary barriers were modeled as 210 and 220 cm-thick. The secondary barriers were 90 cm-thick. The maze wall was modeled also as a wall of 70 cm-thick. The ceiling and a floor were 110 and 150 cm-thick respectively.

The door was modeled as a tandem of lead, steel and polyethylene layers. A first lead layer 1 cm thick, followed for a polyethylene layer of 5 cm-thick of 0.92 g/cm^3 density, the second lead layer was 1 cm thick, and finally a 1 cm-thick layer of 7.92 g/cm^3 density of steel to the outside of the room. The Linac head was modeled as a 10.5 cm tungsten sphere with a cone aperture, the head center was located 1 m over the isocenter, in the figure1 is shown the radiotherapy room geometry and also the location of the neutron detectors.

The calculations were carried out for 47 energy bins according to ICRP 74 [7]; as neutron source term the Tosi *et al* [8] function was utilized, which accounts the neutrons generated by the evaporation and direct or knock-on reactions.

Neutron spectra were calculated in 16 point-like neutron detectors located in the plane at 100 cm under the isocenter in different positions, shown in figure 1. 15 detectors were located inside de radiotherapy room, along the maze and 1 positioned outside the door as is showed in the table I. Also were calculated the neutron spectra for a second energy distribution with 26 energy bins according to NSDuaz code [6].

3. Results and Discussions

In the figure 2, are displayed the neutron spectra, inside the vault room for 5 different detectors. Here can be noticed that thermal neutrons remain constant regardless the distance while epithermal and fast neutrons decreases as the distance of the detector from the source is increased.
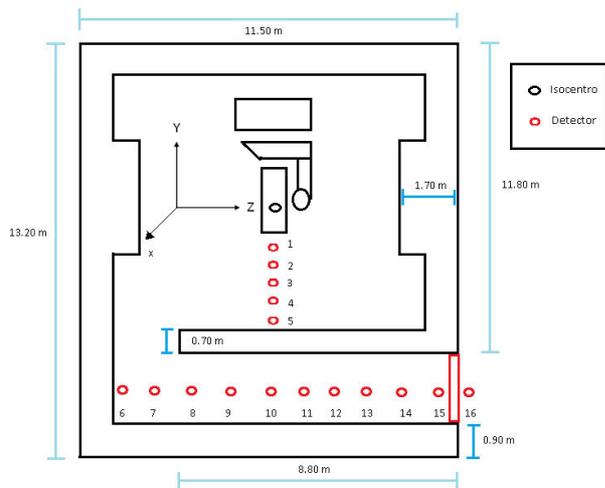
TABLE I. Radiotherapy Room geometry and detector setup

Detector/ coordinates	x	y	z
1	-100	-50	0
2	-100	-100	0
3	-100	-200	0
4	-100	-300	0
5	-100	-400	0
6	-100	-665	-450
7	-100	-665	-350
8	-100	-665	-250
9	-100	-665	-150
10	-100	-665	0
11	-100	-665	100
12	-100	-665	200
13	-100	-665	300
14	-100	-665	400
15	-100	-665	500
16	-100	-665	570

Figure 3 shows the neutron spectra for detectors located along the maze and outside the door. Is shown that the spectra keep the same shape, and for the low energy neutrons and for the peak around 1E(-1) MeV decreases as the detector approaches to the vault room door, that due to the interaction of the neutrons with the medium so the detector 15 located on the door inside the bunker detect less neutron than the one in the beginning of the maze, and therefore detector 16, located outside the door detect, a minor neutron quantity due to the attenuation provided by the door.

Table II show the ambient dose equivalent, H*(10), estimated for the 16 neutron detectors located in the vault room, those calculations were carried out, taking the enough number of stories to achieve uncertainty of 3.0%.
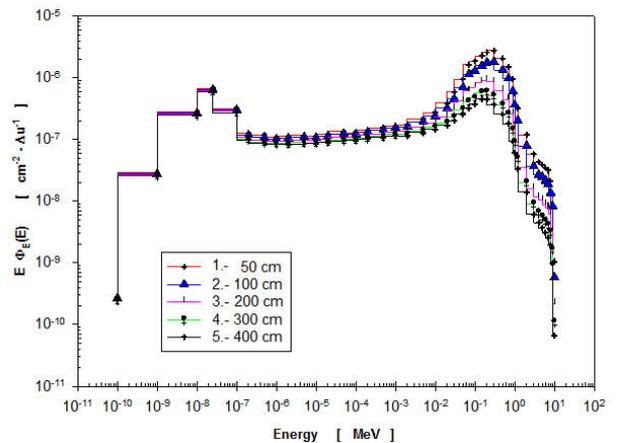

FIGURE 1. Radiotherapy Room geometry and detector setup.
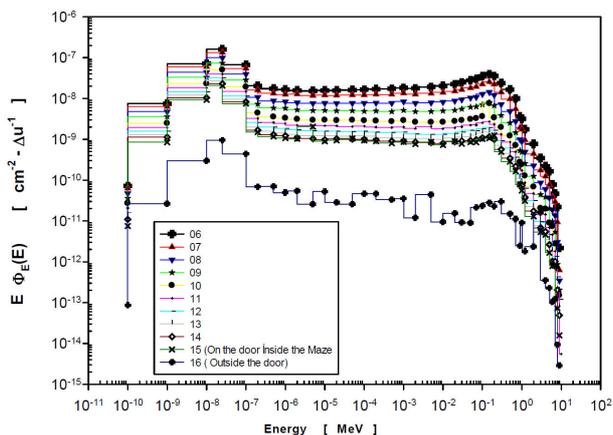

FIGURE 2. Neutron spectra inside de hall.

FIGURE 3. Neutron Spectra along the Maze and outside the vault room door.

We can observe the H*(10) values for the 1 and 2, detectors are 1.64×10^{-3} and 1.10×10^{-3} pSv per neutron emitted by in the LINAC's head (Q).

4.   Conclusions

The photoneutron spectra and H*(10) inside a vault room with an 18 MV Linac were calculated using Monte Carlo methods. In the treatment hall, as the distance respect to the isocenter is increased, the amount of neutrons and the H*(10) are reduced, thermal neutrons remains constant regardless the distance respect to the isocenter due to the room-return effect as has been pointed out in the literature [9-11], as the distance is increased the peak in the high energy region tends to shift to lower region peaking in 0.1 MeV.

Along the maze the spectra are dominated by epithermal and thermal neutrons that contributes to produce activation and the production of prompt gamma-rays. Here the amount of neutrons is reduced as the distance is increased. Behind the door the amount of neutrons is the smallest.

TABLE II. Neutron Detector location inside the radiotherapy

Detector	Ambient dose equivalent H*(10) [pSv/Q]
1	1.64E-03
2	1.10E-03
3	5.52E-04
4	3.49E-04
5	2.65E-04
6	2.39E-05
7	1.58E-05
8	9.34E-06
9	5.76E-06
10	3.48E-06
11	2.42E-06
12	1.85E-06
13	1.45E-06
14	1.20E-06
15	1.12E-06
16	4.70E-08

Those neutron spectra produces a no negligible ambient dose equivalent, where the H*(10) obtained are in the range of 1E(-3) to 1E(-6) pSv per Q, so is necessary to take the appropriate actions to reduce de neutron exposure for the patient and particularly for the radiotherapy room working staff.

Acknowledgments

1. K. Amgarou, V. Lacoste, A. Martin, B. Asselineau, and L. Donadille, *IEEE Trans. Nucl. Sci.*, **56** (2009) 2885.

2. J.B. Awotwi-Pratt, N.M. Spyrou, *J. Radioanal. Nucl. Chem.*, **27**1 (2007) 679

3. C. Domingo, M.J. Garcia-Fuste, E. Morales, K. Amgarou, J.A. Terrón, J. Rosello, L. Brualla, L. Nuñez, R. Colmenares, F. Gómez, G.H. Hartmann, F. Sánchez- Doblado, F., Fernández, *Radiat. Meas.*, **45** (2010) 1391.

4. F. Fernández, C. Domingo, K. Amgarou, J. Castelo, T. Bouassoule, M.J. García, E. Luguera, *Radiat. Prot. Dosim.*, **126** (2007) 361.

5. A. Ma, J. Awotwi-Pratt, A. Alghamdi, A. Alfuraih, N.M. Spyrou, *J. Radioanal. Nucl. Che*m., **276** (2008) 119

6. M.R. Martínez-Blanco, J.M. Ortiz-Rodriguez, H.R. Vega-Carrillo, H.R. Una nueva herramienta de cómputo para la es-

pectrometría y dosimetría de neutrones. Memorias del XX Congreso Anual de la Sociedad Nuclear Mexicana, (2009).

7. ICRP. *Conversion Coefficients for Use in Radiological Protection against External Radiation.* Publication 74. Ann. ICRP **26** (1996) 199.

8. G. Tosi, A. Torresin, S. Agosteo, A. Foglio-Para, V. Sangiust, L. Zeni, M. Silari, *Med. Phys.*, **18** (1991) 54.

9. H.R. Vega-Carrillo, V.M. Hernández-Dávila, E. Manzanares-Acuña, E. Gallego, A. Lorente, M.P. Iñiguez, *Radiat. Prot. Dosim*, **126** (2007) 408.

10. H.R. Vega-Carrillo, E. Manzanares-Acuña, M.P. Iñiguez, E. Gallego, A. Lorente, *Radiat. Meas.*, **42** (2007) 413.

11. X-5 Monte Carlo Team, "MCNP- *A General Monte Carlo N-Particle Transport Code*", Version 5. Los Alamos National Laboratory Report LA-UR-03-1987 (2003).