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Electroneutrons around a 12 MV LINAC

H.R. Vega-Carrillo[1/*], L.H. Pérez-Landeros[2]

[1]Unidad Academica de Estudios Nucleares de la UAZ, Apdo. Postal 336, 98000 Zacatecas, Zac. Mexico
[2]Instituto Zacatecano del Tumor, AC. C. Lago de la Encantada 294, Fracc. Lomas del Lago, Zacatecas, Zac. Mexico

Abstract: Neutron contamination around LINACs for radiotherapy is a source of undesirable doses for the patient. The main source of these neutrons is the photonuclear reactions occurring in the LINAC head and the patient body. Electrons also produce neutrons through (e, e'n) reactions. This reaction is known as electrodisintegration and is carried out by the electron scattering that produce a virtual photon that is absorbed by the scattering nucleus producing the reaction e + A → (A-1) + n + e´. In this work the electron-neutron spectrum to 100 cm from the isocenter of a 12 MV LINAC has been measured using a passive Bonner sphere spectrometer in a novel procedure named Planetary mode.

Keywords: Electroneutrons; LINAC; Spectrum; Passive; Bonner sphere

1. Introduction

Cancer kills more people than Malaria, Tuberculosis and the Human immunodeficiency virus combined. [1, 2]

Although new techniques are continually under study and development to treat cancer, radiotherapy with photon and electron beams produced in linear accelerators, LINACs, is the most diffused medical technique. [3-5]

Approximately 50% of worldwide cancer cases are treated with LINACs. In developed countries 90% of cancer patients are treated with linear accelerators. [6]

When LINACs are operated above 6 MV neutrons are produced through (e, n) and (γ, n) reactions. [7-9]

Neutrons, particularly thermal neutrons, also induce activation in the patient body, materials and air inside the treatment room.

In order to determine the neutron features around the LINACs several works have been carried out, using Monte Carlo calculations and experimental procedures; all of them have been addressed to photoneutrons however, at the best of our knowledge, there is not studies involving electroneutrons probably because the cross section for electroneutron production is approximately 137 times smaller than cross section for photoneutron production. [10]

* E-mail corresponding author: fermineutron@yahoo.com
Telephone: +52-(492)-922 7043 X 119
Fax: +52-(492)-922 7043 x 120

Electroneutrons are produced through the inelastic electron scattering and through electrodisintegration where an electron, with energy E_i, interacts with the Coulomb field of a nucleus, A, being scattered, in an angle θ, with an energy E_f emerging a virtual photon with energy $h\nu = E_i - E_f$. Mean feature of virtual photon is that is not independent of its source and do not satisfy E = p c, where E is the photon´s energy and p is the photon´s momentum. The virtual photon will interact with the nuclei A to initiate the reaction e + A → (A-1) + n + e´, [11] this reaction can be written as A(e, e'n)(A-1) or ${}_{Z}X^{A}(e, e'n){}_{Z}X^{A-1}$. These reactions have been poorly investigated. [12, 13]

The radiator nuclei have a non-spherical charge distribution due to nucleons clusterization, thus the electric and magnetic field of the virtual photon interacts with the nucleus electric and magnetic multipoles. This neutron-generating process is more likely to occur in low Z-nuclei plasma as the ^{9}Be. [13]

Depending upon its energy neutrons around LINACs induce different nuclear reactions in the LINAC components, bunker walls, air and body patient. This radiation is an issue of primary concern for radiation protection.

The aim of this work was to measure the neutron spectrum induced through ${}_{Z}X^{A}(e, e'n){}_{Z}X^{A-1}$ nuclear reactions in a 12 MV linac.

2. Materials and Methods

During LINAC operation inside the bunker a strong, mixed and pulsed radiation field is produced; in such conditions radiation survey devices based upon active detectors are useless, to overcome this drawback the survey

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apparatus must use a passive detector. In this work a Bonner sphere spectrometer, BSS, with 0, 2, 3, 5, 8, 10 and 12 inches-diameter polyethylene spheres. At the center of each sphere pairs of thermoluminiscent dosimeters, TLD600 and TLD700, [14] were used as thermal neutron detector. Measurements were carried out with a Varian 2100CD 12 MV LINAC at Servicios Oncologicos de Aguascalientes.

2.1. Monte Carlo calculations

In order to use the BSS in planetary mode a Monte Carlo calculation, using the MCNP5 code [15], was carried out to evaluate the isotropy of neutron spectra around the IC and the cross talking between the spheres located around a 100 cm radius circle with the centre at the isocentre.

To evaluate the neutron field isotropy a full scale model of concrete bunker with a LINAC head modelled as a 10 cm-thick W shell [10] with a point-like neutron source term [16] at the centre was used. In the model was included the 30x30x15 cm^3 solid water phantom and the neutron spectra around a 100 cm-radius circle were calculated.

To evaluate the spheres cross talking in the above model the polyethylene spheres were modelled and the neutron spectrum was estimated in a point located 100 cm from the IC, this point was between the 10 and 12 inches-diameter spheres. The angles between the spheres were varied from 10 up to 60^o

2.2. Neutron spectrum measurements

During the measurements a 12 MeV electron beam was used to deliver 12 Gy_e, using 3 Gy_e/min, to the isocenter that was located 5 cm depth in a 30x30x15 cm^3 solid water phantom; the irradiation area at the isocenter, IC, was 20x20 cm^2. Bonner spheres, each with two TLD600 and two TLD700, BSS/TLDs, were distributed along the perimeter of a 1 m circle with its centre at the IC in 45^o angles as shown in Figure 1. Before the measurements the TLDs were heated by 1 hour to 400 ^oC.

The TLDs readout were obtained with a TLD reader Harshaw 3500 where were heated from 50 to 300 ^oC, in nitrogen ambient, with a temperature gradient of 10 $^oC/s$. For each sphere the mean value of TLD600 readouts were calculated and corrected by the mean values of two pairs of TLD600 used to measure the background; the same procedure was applied to the TLDs700. For each sphere the net neutron signal, Sn, was obtained using equation 1. The standard deviations were calculated using equation 2.

$$Sn = L600 - k\,L700 \qquad (1)$$

$$\sigma_{Sn} = \sqrt{\sigma^2_{L600} + L700^2\,\sigma^2_k + k^2\,\sigma^2_{L700}} \qquad (2)$$

In these equations L600 and L700 are the background corrected average readouts of TLD600 and TLD700, σ_{L600} and σ_{L700} are the respective standard deviations, k is the response to γ of TLD600-to-response to γ of TLD700 ratio, and σ_k is its standard deviation. The set of seven Sn values and their standard deviations were used as input in the BUNKIUT unfolding code [17] and the neutron spectrum was calculated.

Figure 1. BSS/TLDs around the IC

3. Results and Discussion

3.1. Monte Carlo calculations

From the first calculation the neutron spectrum at any point located 1 m from the IC was the same.

From the second set of calculations the neutron spectrum was different when the 10 and 12 inches-diameter spheres were close. This effect disappeared when the angles were larger than 20^o.

3.2. Neutron spectrum measurements

Using the BSS/TLDs in planetary mode the neutron spectrum was measured to 100 from the IC, the neutron spectrum is shown in Figure 2.

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These neutrons were produced during the interaction of 12 MeV electrons with the radiator in reactions A(e, e'n)(A-1).

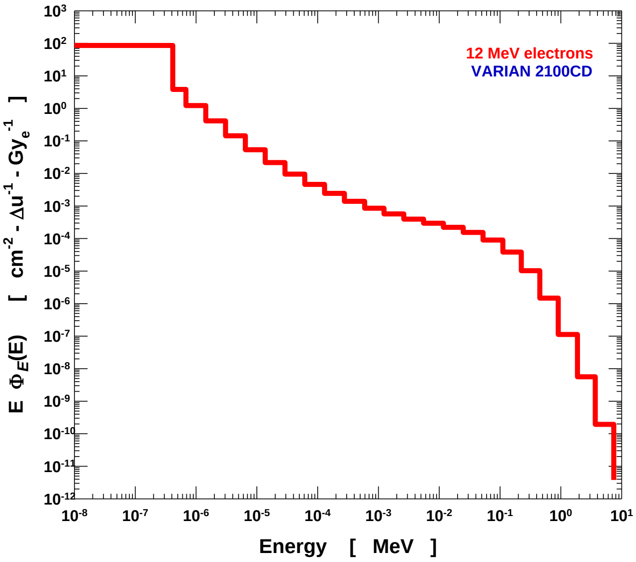

Figure 2. Neutron spectrum

The neutron fluence is ϕ = 324 ± 42 n/cm^2-Gy_e, the ambient dose equivalent is H*(10) = 3.73 ± 0.57 nSv/Gy_e.

4. Discussion

4.1. Symmetry and Cross talking

The primary and secondary barriers are to the same distances from the isocentre, the main difference is the wall adjacent to the maze, because there is the access doorway between the LINAC hall and the maze [18, 19] nevertheless the neutron spectra show symmetry around a 1 m radius circle with its centre at the IC.

When neutrons are transported from the LINAC head, the phantom and the bunker walls to the room eventually will reach the polyethylene spheres of the BSS/TLDs spectrometer, some neutrons are scattered out from the spheres as a perturbation agent on neutron field; this effect is larger for the bigger spheres. From the calculations was found that in a point located between the two bigger spheres this perturbation was negligible when the angles were larger than 20^o.

When the bunker is symmetric the BSS/TLD can be used in planetary mode locating the spheres in angles larger than 20^o. The advantage of this method is that a single shot of LINAC is required to get the neutron spectrum.

4.2. Electroneutron spectrum

As can be noticed from Figure 2 thermal neutrons are the main component and from 3 to 7 MeV neutrons are the less frequent component. This spectrum is different to the photoneutron spectrum which has a peak around 1 MeV and another peak in the thermal region [20]. Probable explanation of electroneutron spectrum is as follows: During electron scattering the electron must lose between 7 to 8 MeV that is converted in the virtual photon that is absorbed by the nucleus, this energy is enough to separate a neutron from tungsten nuclei, any energy above this value shows up as neutron kinetic energy, that in this case is between 4 to 5 MeV.

In this interaction few neutrons are emitted from the electron beam scatterer, that in this case is the scattering foil that is used in the LINACs to broad the electron beam from a pencil beam to a Gaussian profile; this is a thin foil made of high Z materials like W. Also, the cross section to produce (e, e'n) reactions is 137 times smaller than (γ, n) reactions [10] therefore a small neutron fluence is produced.

Once electroneutrons are produced they are transported through the head losing a small amount of energy, then reach the bunker walls and are scattered back to the hall with lesser energy, thus the measured neutron spectrum shows a large contribution of neutrons with epithermal and thermal energies [20].

The combination of the small thickness of the scattering foil and the small cross section for the (e, e'n) reactions is the probable explanation of the small neutron fluence measured.

5. Conclusions

The BSS/TLD spectrometer, in planetary mode, was used to measure the electroneutron spectrum to 1 m from the IC located 5 cm deep in a solid water phantom.

In this mode the information required to obtain the neutron spectrum only requires a single LINAC shot. The drawback of this method is that symmetry of the bunker and polyethylene spheres cross talking must be evaluated.

When a 12 MV LINAC is operated in electron beam mode neutrons are produced mostly being thermal.

To 1 m from the IC the total neutron fluence and the ambient dose equivalent are 324 ± 42 n/cm^2-Gy_e abd 3.73 ± 0.57 nSv/Gy_e respectively.

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