Applied Radiation and Isotopes 117 (2016) 2–7

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Neutron H*(10) estimation and measurements around 18 MV linac

Pablo Víctor Cerón Ramírez [a,*], José Antonio Irán Díaz Góngora [a], Lydia Concepción Paredes Gutiérrez [b], Teodoro Rivera Montalvo [a], Héctor René Vega Carrillo [c]

[a] Instituto Politécnico Nacional, Centro de Investigación en Ciencia Aplicada y Tecnología, Avanzada Legaria, Calzada Legaria No. 694, 11500, México
[b] Instituto Nacional de Investigaciones Nucleares, Carretera México-Toluca s/n, 5275 Ocoyoacac, México
[c] Universidad Autónoma de Zacatecas Unidad Académica de Estudios Nucleares, Apdo. Postal 336, 98000 Zacatecas, México

HIGHLIGHTS

- H*(10) measurements in three points were carried out around 18 MV linac.
- NCRP 151 equations allowed to estimate the dose at the door and the source strength.
- A MCNPX model of the linac head was developed to calculate H*(10) due to photoneutrons.
- The measurements and MCNPX calculation were compared.

ARTICLE INFO

Article history:
Received 31 October 2015
Received in revised form
4 May 2016
Accepted 9 May 2016
Available online 11 May 2016

Keywords:
Neutron dosimetry
LINAC
Monte Carlo

ABSTRACT

Thermoluminescent dosimetry, analytical techniques and Monte Carlo calculations were used to estimate the dose of neutron radiation in a treatment room with a linear electron accelerator of 18 MV. Measurements were carried out through neutron ambient dose monitors which include pairs of thermoluminescent dosimeters TLD 600 (^{6}LiF: Mg, Ti) and TLD 700 (^{7}LiF: Mg, Ti), which were placed inside a paraffin spheres. The measurements has allowed to use NCRP 151 equations, these expressions are useful to find relevant dosimetric quantities. In addition, photoneutrons produced by linac head were calculated through MCNPX code taking into account the geometry and composition of the linac head principal parts.

1. Introduction

The measurement of neutrons produced as secondary radiation is a necessary task in each high energy linac facility due to the differences presented in the geometry and the material composition between different treatment rooms and even the machines with the same type (Ghasemi et al., 2015). Working above 10 MV linacs produce undesirable neutrons therefore there is a need of better dosimetric systems inside the linac's bunkers (Esposito et al., 2008). Nevertheless photoneutron contamination is also present in linacs with lower voltages, becomes important beyond 10 MV (NCRP, 2005).

Photoneutrons are generated when the linac produces X-rays by bremsstrahlung. These high energy photons impinge on the nucleus of the target, flattened filter, collimator and other linac head components. If energy exceeds the threshold (8 MeV average for high Z materials) photonuclear reactions are produced through a phenomenon known as giant dipole resonance and photoneutrons are liberated (Chu et al., 2011).

Neutrons interact with the equipment in the treatment room, and the patient becoming a radiation protection issue. The neutron energy distribution, or spectrum has a peak between 0.1 and 1 MeV being very effective for tissue damage since they have a weight factor of the radiation of $W_R = 20$ which is the maximum in the calculation of dose equivalent and effective dose equivalent (Ma et al., 2008) which induces an additional not desired dose to healthy tissues.

Several works have been published in the aim to measure the neutron spectrum and the dose around linacs, due to the radiation field inside the treatment room, the neutron measuring devices are based upon passive detectors, that are combined with the neutron spectrum estimation using Monte Carlo methods. In linac modeling works go from simple head model (Vega-Carrillo and Baltazar-Raigosa, 2010) until a detailed model (Ma et al., 2008). Ghiasi and Mesbahi (2010) did a comparison between both models

* Correspondence to: Centro de Investigación en Ciencia Aplicada y Tecnología, Avanzada Unidad Legaria, Av. Legaria 694, Col. Irrigación, C.P.11500 México DF, México.
E-mail address: victceronr@hotmail.com (P.V. Cerón Ramírez).

http://dx.doi.org/10.1016/j.apradiso.2016.05.006
0969-8043/© 2016 Elsevier Ltd. All rights reserved.

concluding that when a detailed head is used the results have better accuracy allowing determining the photoneutrons origin. Most recent publications are supported by measurements and complemented by Monte Carlo calculations, Alem-Bezoubiri et al. (2014) did use a detailed geometric model of the head of a Varian Clinac 2100C using a source term the Tosi et al. (1991) function containing evaporation and knock off neutrons. For neutron measurements they used track detectors CR-39. Nedaie et al. (2014) with the pairs of thermoluminescent dosimeters (TLD 600 and TLD 700) technique, measured the neutron dose under the field produced by the Varian Clinac 2100C and Elekta Precise Linac. Measurements in this study, made a phantom of perspex in the central axis of the photon field, a model of the two heads is also generated by MCNPX code and the authors concluded that the TLDs are not useful for measuring the dose due to neutron under these conditions. By contrast with the Monte Carlo method they achieved best estimates with an uncertainty $<2\%$. There is also a particular interest in developing and deploying neutron detectors, in the work of Vega-Carrillo et al. (2014a) a passive neutron area monitor was developed. This passive neutron area monitor has pairs of TLDs as thermal neutron detector allocated in the center of a polyethylene cylindrical moderator. It was evaluated measuring the ambient dose equivalent ($H^{*}(10)$) in a 15 MV linac and in the beam port of a TRIGA Mark III reactor (Vega-Carrillo et al., 2014b).

An important issue to consider is the design and the evaluation of the facilities where the linacs are installed. In the report 151 of the NCRP (2005) are displayed analytical methods which the dimensions of the room are related with: the dose equivalent in the door, the source strength and neutron fluence in the entrance of the maze. Therefore the production of photoneutrons, their distribution around linacs, and the dosimetric implications for patients and staff still remains a topic of interest. In this study it is suggested to use several well-known techniques and use them as complementary methods to obtain the relevant quantities in the design and radiological protection of a treatment room with a linac of 18 MeV.

The aim of this work is to estimate neutron ambient dose equivalent ($H^{*}(10)$) in several points of the Novalis Tx treatment room as well as calculate photoneutrons production on the linac head for radiation protection purposes, where thermoluminescent dosimetry, analytical methods and Monte Carlo simulation were used.

2. Materials and methods

2.1. Neutron detector

The TLD pairs technique was used in combination with a moderator item. The thermal neutron detector was made using 2 pairs of $3.2\times3.2\times0.89$ mm ribbon type thermoluminescent dosimeters (600 and 700). The TLD 600 is sensitive to thermal neutrons and photons because it was enriched with 95.62% of ^{6}Li (943.2 barns), and the TLD 700 is sensitive to photons with a low cross section for thermal neutrons (14.7 barns) since it was enriched with the 99.93% of ^{7}Li (Hsu et al., 2010, Vega-Carrillo, 2002).

Evaporation and knock off neutrons from the linac are transported in the treatment room loosing energy and epithermal and thermal neutrons are produced. At any point in the treatment room the amount of fast neutrons is reduced as the distance from the isocenter is increased, meanwhile epithermal and thermal neutrons remain constant (Vega-Carrillo et al., 2007; Benites-Rengifo, 2014). Therefore a 20 cm-diameter paraffin sphere (density 0.93 g/cm^{3}) was built and at its center pairs of TLDs were sited using an acrylic container (Barquero et al., 2005). Before each irradiation TLDs were heated to 400 °C during 1 h, followed by 2 h to 100 °C in order to remove any background signal. After the irradiation the TLDs readouts were obtained with a Harshaw 3500 reader.

The homogeneity of TLDs was obtained using 1 Gy of photons from a 6 MV linac, and a 185 GBq ^{239}PuBe source. Those TLDs whose responses were scattered within 5% from the mean response were selected. The net neutron response was obtained using TLD 600 signal for photons and gammas, $R_{600}^{n+\gamma}$, and the response of TLD 700, R_{700}^{γ}, Eq. (1) (Esposito et al., 2008; Nedaie et al., 2014; Vega-Carrillo, 2002).

$$R_n = R_{600}^{n+\gamma} - kR_{700}^{\gamma} \qquad (1)$$

In Eq. (1) k is the ratio between the response to gammas of TLD600 and the response to gammas of TLD 700, as is shown in Eq. (2),

$$k = \frac{R_{600}^{\gamma}}{R_{700}^{\gamma}} \qquad (2)$$

The detectors (pairs of TLDs on the paraffin spheres) were calibrated using the neutron field from the radial port beam of the TRIGA Mark III reactor at the Instituto Nacional de Investigaciones Nucleares (ININ). The neutron spectrum has a mean energy of 0.816 MeV and the Ambient dose equivalent rate is 934 ± 55 mSv/h (Vega-Carrillo et al., 2014b).

The idea of using the neutron spectrum of TRIGA reactor beam port was because it includes neutrons from thermal up to 10 MeV and its features were also known as is reported in the mentioned reference. The scattering component was not measured (no needed). Because we are using pairs of TLDs the gamma-ray contribution is considered.

The detectors were calibrated using Eqs. (3) and (4) (IAEA, 2000).

$$H^*(10) = R_n FC \qquad (3)$$

$$FC = \frac{H^*(10)_{port}}{R_{n(port)}} \qquad (4)$$

In the Eqs. (3) and (4) $H^*(10)$ is the Ambient dose equivalent at a selected point and R_n is the TLD neutron response in that point. The calibration factor FC is calculated under reference conditions through the ratio between the Ambient dose equivalent at the irradiation port $H^*(10)_{port}$ (known field of reference) and the measured value at the irradiation port $R_{n(port)}$, see Eq. (4).

2.2. H*(10) measurements in a linac treatment room

Irradiation was performed in the Novalis Tx treatment room in the Hospital ABC (The American British Cowdray Medical Center) at Mexico city, Fig. 1 shows the linac head, and detectors 1, 2 and 3.

Using 18 MeV photons the linac delivered 5 Gy (300 cGy/min) at the isocenter. The H*(10) was measured in three different points, the detector 1 was located at isocenter, detector 2 was placed one meter from isocenter (1.41 m from the target), see Fig. 1 (a), and the position of the detector 3 was at the inner entrance maze, see Fig. 1(b). Different irradiation features were applied, like field size, dispersion medium (phantom) and gantry rotation see Table 1. Three trials were made in each point for calculating statistical deviation.

2.3. Analytical methods

The NCRP report 151 (2005) provides a methodology for designing and evaluating the shielding of radiotherapy facilities