Neutron spectra and H*(10) around an 18 MV LINAC by ANNs

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Abstract

Neutron spectra and ambient dose equivalent H*(10) were calculated for a radiotherapy room in 16 point-like detectors, 15 located inside the vault room and 1 located outside the bunker. The calculation was carried out using Monte Carlo Methods with the MCNP5 code for a generic radiotherapy room model operating with a 18 MV Linac, obtaining 16 neutron spectra with 47 energy bins, the H*(10) values were calculated from the neutron spectra by the use of the fluence-dose conversion factors. An Artificial Neural Network (ANN) were designed and trained to determine the neutron H*(10) in 15 different locations inside the vault room from the H*(10) dose calculated for the detector located outside the room, using the calculated dose values as training set, using the scaled conjugated gradient training algorithm The mean squared error (mse) set for the network training was 1E(-14), adjusting the data in 99.992 %. 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. The results shows the using this Artificial Intelligence technic as a useful tool for the neutron spectrometry and dosimetry by the simplification on the neutronic fields characterization inside radiotherapy rooms avoiding the use of traditional spectrometric systems. And once the H*(10) doses have been calculated, to take the appropriated actions to reduce or prevent the patient and working staff exposure to this undesirable neutron radiation

Keywords: Neutron spectrometry, Neutron dosimetry, Radiotherapy, Artificial Neural Networks.

1. Introduction

Since the 30's due to the improvements on neutron spectrometry, developments on the nuclear physics fields, as the radiotherapy and radiologic protection have been promoted. Neutron spectrometry or knowing some information about the neutron spectra is needed in order to evaluate the operational and protection quantities as the ambient, personal or in organ equivalent doses or effective dose (Domingo *et al.*, 2010).

Radiation spectrometry includes the measurements of radiation field respect his mass, energy, frequency, momentum, angle, wave length etc., the final result of spectrometry is the radiation spectra, which includes the necessary information to know the radiation field of interest (Vega-Carrillo et al., 2007). From the physic quantities, such as neutron fluence, through the conversion fluence to dose coefficients, dosimetric quantities can be calculated (Domingo et al., 2010).

In the case of the radiotherapy cancer treatment using particle linear accelerators (LINAC's), additionally to the treatment radiation beam, also neutrons are produced originated through photonuclear (γ,n) reactions, which are generated as the photons interact with the heavy materials conforming the accelerator head (Domingo et al., 2010; Amgarou et al., 2009). Those photoneutrons represent a serious problem from the point of view of the radiologic protection, due to the affectation induced to the patients and also can escape the bunker and affect the hospital working staff, though the production of activation and prompt gamma rays. Photoneutrons are generated on LINAC's working with energies greater than 8 MeV, due to the cross section of some materials composing the target, flattening filter, collimators and the gantry shielding, also through the Giant Dipolar Resonance (GDR), for which the energy threshold is about 7 MeV. The resulting photoneutrons contribute to a undesirable radiation dose to the patient been treated with radiotherapy, that's why is very important to carry out the photoneutron field characterization and then to estimate the risk for the patient (Awotwi-Pratt and Spyrou, 2007).

On the field of radiologic protection the study of photoneutrons generated on high energy LINAC's is of great importance because not only the patient but the working staff of the radiotherapy room is exposed to this secondary radiation (Domingo et al, 2010). Additionally, due to the neutrons high biological effectiveness, the maximum for the calculation of equivalent and effective doses (Ma et al., 2008), several authors have associated the possibility of secondary cancers in patients after been treated with radiotherapy (Martinez-Ovalle et al., 2011).

The Artificial Neural Network technology (ANN), on the photoneutron spectrometry and dosimetry has become a useful tool to solve the spectra unfolding problem present on the use of a multielement systems as the Bonner Sphere Spectrometer (BSS) (Vega-Carrillo et al., 2007; Fehrenbacher et al., 1999; Cordes et al., 1998) this because of initial spectra is not needed, which is indispensable for the iterative methods that use the codes SANDII, BUNKI, BUNKIUT, BUNKIUAZ, etc. (Matzke, 2003; Kardan et al., 2003). The use of the artificial intelligence technology represent a time save and simple use, because the neural network require only to be trained once to dispose of the acquired knowledge (Vega-Carrillo et al., 2006a; Vega-Carrillo et al., 2006b).

Neural network models are algorithms for learning and optimization based on the concepts of the human brain nature. In generally an ANN consist of a set of input nodes that are directly linked to a series of output nodes or indirectly through one or more hidden layers of neurons. The net learning process consist on the iterative adjust of their synaptic weights and thresholds, in order to produce the outputs from the inputs to present the closest outputs to the real outputs (Kardan et al., 2003).

The attractiveness of ANN’s comes from the remarkable information processing characteristics of a biological system such as, nonlinearity, high parallelism, robustness, fault and failure tolerance, learning, ability to handle fuzzy and imprecise information and the generalization capability (Bassher and Hajmer, 2000).

The goal of this work is to design and to train an artificial neural network capable to determine the ambient dose equivalent dose H*(10) on 15 locations around an 18 MV LINAC and along the maze of a radiotherapy room, from only H*(10) value obtained outside the room.

2. Materials and methods

One of the essential requirements for the use of the technology or ANN', is to have reliable and representative data of the problem, as they can be used to train the network and then determine the adequate network topology to obtain similar output values to the target values within a selected range. In this work the training data were obtained by Monte Carlo Methods. Once the training data is obtained, by trial and error the network topology to be used in the ANN was found.

2.1. Monte Carlo calculation

Ambient dose equivalent H*(10) were calculated for 16 point like detectors located on different places inside and outside a generic radiotherapy room were calculated by Monte Carlo MCNP5 code. This code models the radiation transport phenomena by the use of a random number generator, this way simulating in detail the particle interaction processes, until they scape or are absorbed by the environment, providing the same information as a real experiment (Rogers, 2006). Some of the characteristics of the radiotherapy room modeled are shown in Figure 1.

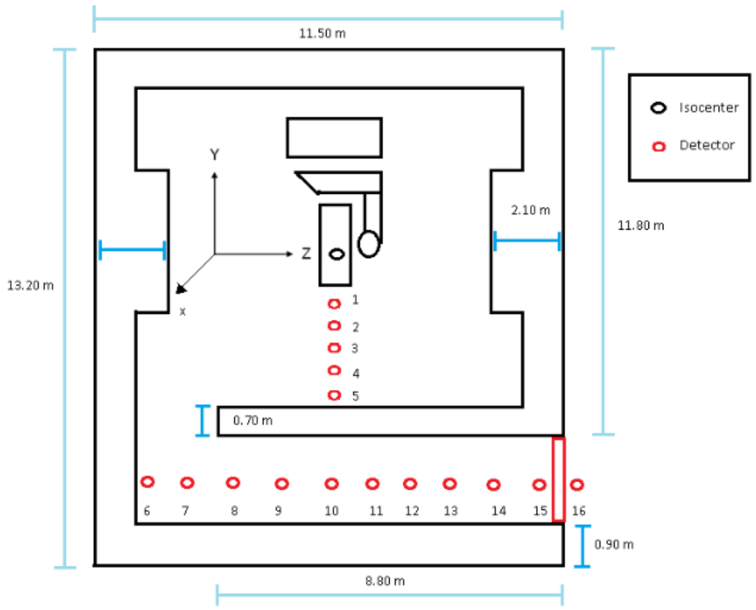

Figure 1. Radiotherapy room and detector locations

For all detectors 47 energy bin neutron spectra were calculated in the range from 1E(-9) to 20 MeV. The H*(10) doses were calculated using the fluence to dose ICRP 74 conversion factors (ICRP, 1996).

2.2. Artificial Neural Network

Using trial and error method a multilayer feedforward network was selected, the net is composed of 3 hidden layers of 25, 25, and 15, neurons respectively, additionally to the input layer made of 1 neuron, and an output layer of 15 nodes. This topology was selected after several tests of networks with different topologies and characteristics as the activation function, number or neurons in each layer and the desired approximation error.

The ANN was designed and trained in to the MATLAB programming environment making use of the Neural Network Toolbox 6. The training was carried out using the scaled conjugated gradient backpropagation training algorithm (SCG) (Moller, 1993), which reduces in at least one magnitude order the required time to carry out the training stage.

3. Results and discussion

Neutron spectra and ambient dose equivalents were calculated for 16 point-like detectors inside and outside a generic radiotherapy room modeled by MCNP5 code. The spectra was calculated using the Tosi et al function (Tosi et al., 1991), which accounts the photoneutrons generated by direct reaction and nuclear evaporation process the photons interacting to the heavy materials conforming the accelerator head. In figure below shows the neutron spectra obtained for the detectors 1, 2, 3, 4, 5.

In Figure 2, shows spectra has two main peaks, one in the thermal range an another between 0.01 to 1 MeV, after 1 MeV energy there is a protuberance due to the knock-on neutron reaction production. The 0.01 to 1 MeV peak is formed by the nuclear evaporation neutron production process, while the thermal and epithermal neutrons are the particles that once outside the accelerator head interact with the room walls, roof and ceiling and constitute the room-return neutrons, which are characterized by their magnitude is independent of the distance

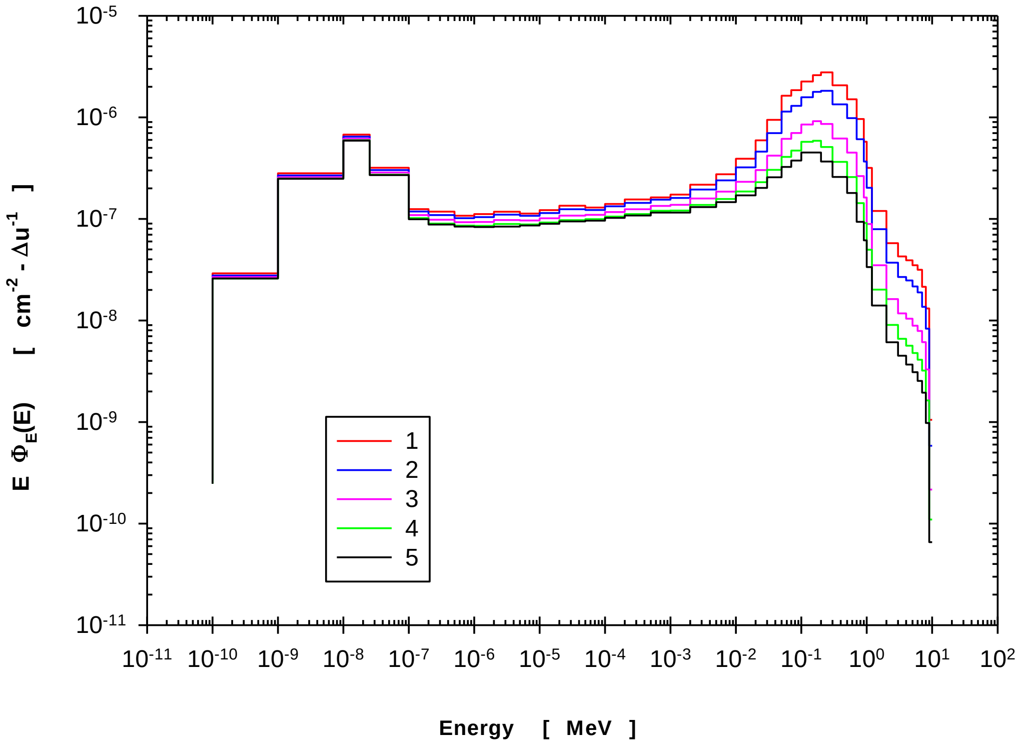

Figure 2. Neutron spectra around the LINAC en detectors 1, 2, 3, 4, 5.

On Figure 3, are shown the neutron spectra calculated by Monte Carlo methods for the detectors located along the maze on the radiotherapy room.

Additionally, on the maze spectra the evaporation neutrons peak and the knock-on neutrons protuberance are reduced by the effect of the distance, and the main neutron group is the thermal neutrons. The calculated spectra in this work are similar to the reported in the literature (Hernández-Adame et al., 2011).

Then, using the neutron spectra and the ICRP 74 fluence to dose conversion factors, the ambient dose equivalent H*(10) were obtained for all 16 neutron detectors, as is shown in Table 1. This H*(10) values then were used as ANN training set. The net by adjusting their synaptic weights and thresholds, was able to relate the input dose H*(10) = 4.7082E (-8) pSv to the target doses for the 15 point like detectors located inside the vault room with a mean squared error (mse), mse=1E(-14), on the training stage. Resulting in a 99.992 % approximation between the ANN output and the target data as is show in figure 4.

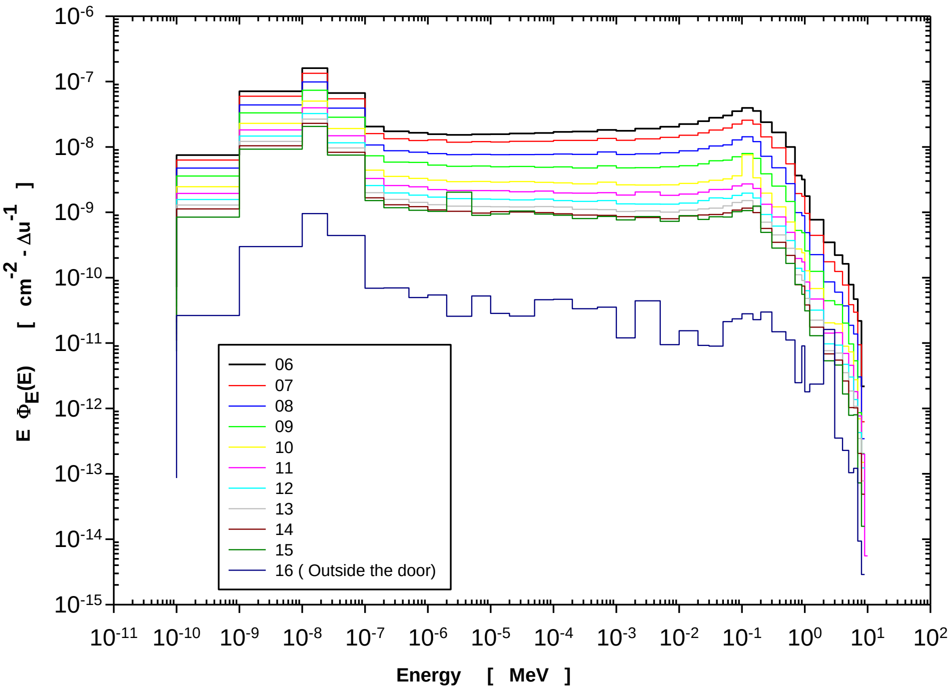

Figure 3. Neutron spectra along the maze

Table 1. Ambient dose equivalent H*(10) for each detector inside the vault room

Detector	H*(10) [pSv/Q]
1	1.6406E-03
2	1.1038E-03
3	5.5200E-04
4	3.4900E-04
5	2.6583E-04
6	2.3905E-05
7	1.5893E-05
8	9.3460E-06
9	5.7647E-06
10	3.4835E-06
11	2.4273E-06
12	1.8502E-06
13	1.4596E-06
14	1.2069E-06
15	1.1183E-06

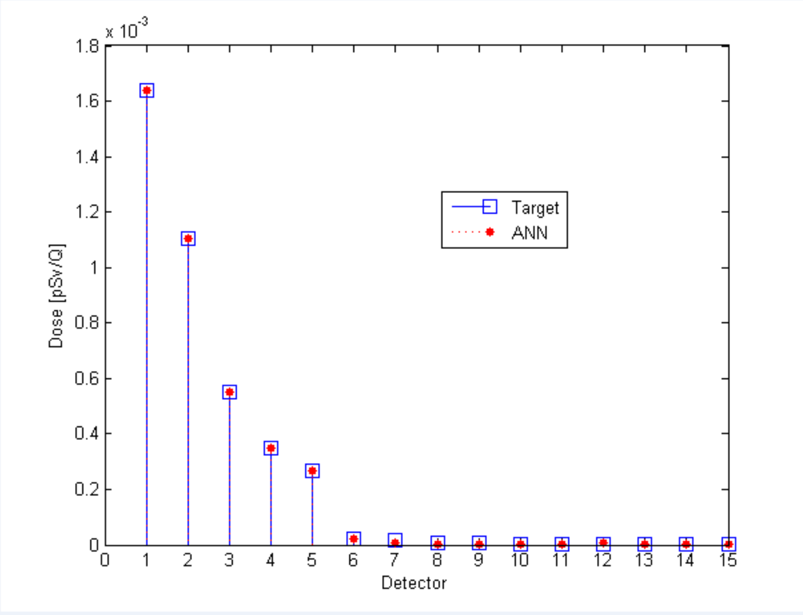

Figura 4. Neural Network output doses versus target doses

In Figure 4 shows the comparative graph between the ANN outputs and the target data, can be seen the similarity between the doses at the ANN output layer with the target doses incident on the input layer of the network been adjusted in 99.992%.

4. Conclusions

MCNP5 code was used to calculate 16 neutron spectra in different locations around a LINAC and along the maze in a radiotherapy room, then the ambient dose equivalent H*(10) values were calculated for each detector. Finally those H*(10) values were used as a training set for an Artificial Neural Network.

Additionally, by the use the MATLAB® computational code, the neural network was trained using (trainscg), backpropagation training algorithm, resulting an ANN capable to obtain 15 neutron H*(10) doses for detectors located inside the radiotherapy room as a response to a input dose in outside the room, H*(10)=4.7082E(-8) pSv/Q.

Neutron spectra calculated by MCNP5 code result similar to the spectra reported for an 18 MV medical linear accelerator (Hernández-Adame et al., 2011).

The use of this neutron dosimetry estimation method could help to simplify the neutron fields characterization process in a radiotherapy room operating 18MV LINACs by only the need of one H*(10) neutron dose measurement outside the room, avoiding the need of carrying out the measurements with heavy spectrometry equipment as the BSS and all the unfolding difficulties associated and also the long time required to carry out the measurements. Finally to know the features of the neutron radiation field present inside radiotherapy room can give us the tools to carry out the appropriated actions in order to minimize the patient and clinic staff to this undesirable radiation associated to the recurrence of secondary cancer.

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