# Neutron area monitor with passive detector

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Using Monte Carlo methods the responses of a passive neutron monitor area has been calculated. To detect thermal neutrons the monitor has a gold foil that is located at the center of a polyethylene cylinder. Impinging neutrons are moderated by polyethylene nuclei reaching the gold foil with the energy to induce activation through the reaction $^{197}$Au(n, $\gamma$) $^{198}$Au. The $^{198}$Au decays emitting 0.411 MeV gamma rays with a half life of 2.7 days. The induced activity is intended to be measured with a gamma-ray spectrometer with a 3" $\emptyset \times$ 3" NaI(Tl) scintillator and the saturation activity is correlated to the ambient dose equivalent. The response was calculated for 47 monoenergetic neutron sources ranging from $1 \times 10^{-9}$ to 20 MeV. Calculated fluence response was compared with the response of neutron monitor area LB 6411.

*Keywords:* Neutrons; Monte Carlo; activation detectors.

Se utilizó el método de Monte Carlo para calcular las respuestas de un monitor de neutrones pasivo. Para detectar los neutrones térmicos el monitor tiene una lámina de oro que se encuentra en el centro de un cilindro de polietileno. Los neutrones que inciden son moderados por los núcleos de polietileno que llega a la lámina de oro con la energía para inducir la activación a través de la $^{197}$Au reacción (n, $\gamma$) $^{198}$Au. El $^{197}$Au decae emitiendo rayos gamma de 0.411 MeV con una vida media de 2.7 días. La actividad inducida se destina a medir con un espectrómetro de rayos gamma con un detector de centelleo de 3" $\emptyset \times$ 3" NaI (Tl) y la actividad de saturación se correlaciona con la dosis equivalente ambiental. La respuesta se calculó para 47 fuentes de neutrones monoenergéticos desde $1 \times 10^{-9}$ a 20 MeV. La respuesta a la fluencia se comparó con la respuesta del monitor de área LB 6411.

*Descriptores:* Neutrones; Monte Carlo; detectores de activación.

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## 1. Introduction

Linear accelerators for medical use, LINAC's, working above 8 MV produce an undesirable neutron field through photonuclear reactions ($\gamma$, n) [1-3] occurring when photons interact with the high Z materials in the LINAC head [4,5]. Neutrons are also produced in bunker's walls and the patient body [1-3]; thus, neutron field in the treatment hall delivers an undesirable dose in the patient's body and represents a radiological risk for staff around the facility. Therefore, the determination of neutron spectra, by calculations or measurements, is important to estimate the neutron dose. To have a good estimation of neutron dose is advisable to measure the neutron spectra and to use the proper neutron fluence-to-dose coefficients; however, in practical situations the dose is measured using a neutron remmeter or a neutron area monitor. The response of neutron dosimeters is function of neutron energy; therefore the dosimeter selection is important because in anthropogenic applications the neutrons's energy range is several orders of to magnitude [6].

Inside the treatment room with a LINAC the radiation field is intense, pulsed, and mixed then a neutron dosimeter with active detector cannot be used, instead are used passive detectors like thermoluminescent dosimeters, track detectors and activation foils [2].

Activation detections for thermal and epithermal neutrons are mostly nuclei that are activated by neutron capture, the activated nucleus decays emitting $\beta$ and/or $\gamma$ particles. Features like half life, isotopic composition, cross section and the decay particle are important when activation foils are selected [3,7].

Gold foils are frequently used as neutron detector, it can be obtained with high purity; it is malleable, chemically stable, has a relative large cross section [7]. $^{197}$Au captures a neutron becoming $^{198}$Au which during decay emits a 411 keV photon with $p_\gamma = 0.9554$. Au is sensitive to thermal neutrons to increase its response to neutrons with different energy, foils are inserted in moderators. [2].

Neutron detectors commercially available are based upon active detectors which are useless in mixed, intense and pulsed radiation field, therefore is important to have neutron monitor with passive detector, to be used in places where the radiation field is pulsed, mixed and intense as those in some hot areas in nuclear power plants, high-energy accelerators, cyclotrons and LINACs for medical applications.

The aim of this work is to calculate the response of a cylindrical area monitor designed to use $^{197}$Au activation foil as thermal neutron detector using Monte Carlo method.

## 2. Materials and methods

MCNP5 code [8] was used to determine the response functions of the monitor area. Geometry was considered a 20.5 $\emptyset \times$ 20.5 cm$^2$ polyethylene cylinder with a density of 0.94 g/cm$^3$ as a neutron moderator. In the center of the moderator is inserted the thermal neutron detector modeled as a $^{197}$Au foil to 99.9999% in purity with a density of

19.32 g/cm$^3$. This foil is 2.54 Ø × 0.00635 cm$^2$. Cross section, purity and half-life were the reasons used to choose Au as thermal neutron detector.

Activation and fluence responses were calculated, to calculate the responses two irradiation geometries were considered: one where the source is modeled as a disk with the same diameter as the moderator and placed above the upper surface of the monitor. Another source was modeled as a square whose cross section is the diameter times the height of the cylinder and is located laterally. The irradiation geometries are shown in Fig. 1.

Also the response functions were calculated using two different position of the activation foil, one with the surface parallel to the source surface and another with the foil's surface perpendicular. The response functions were calculated for 47 mono-energetic neutron sources ranging from $1 \times 10^{-9}$ MeV to 20 MeV.

## 3. Results and discussion

In Fig. 2 are shown the activation response functions of the neutron monitor area for both irradiation geometries and for both foil positions. The response is the amount of activations produced per unit neutron flux and per mg of $^{197}$Au.

The behavior of the curve in Fig. 2 shows the activation reactions generated in the gold foil through interactions with neutrons of different energies when the source is located in the lateral and superior. It can be noticed that regardless the
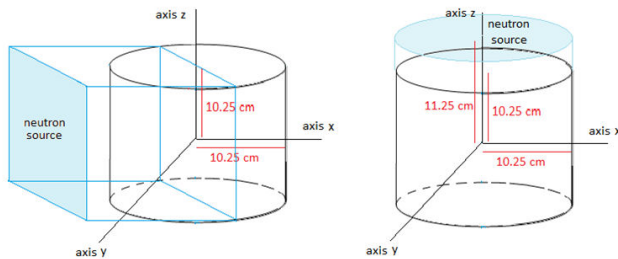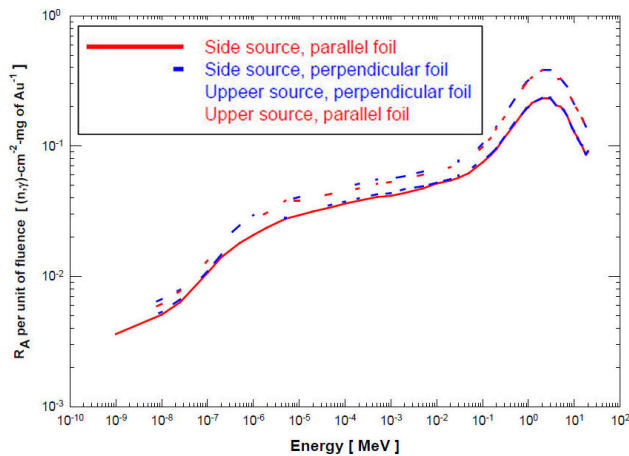


FIGURE 1. Irradiation geometry.



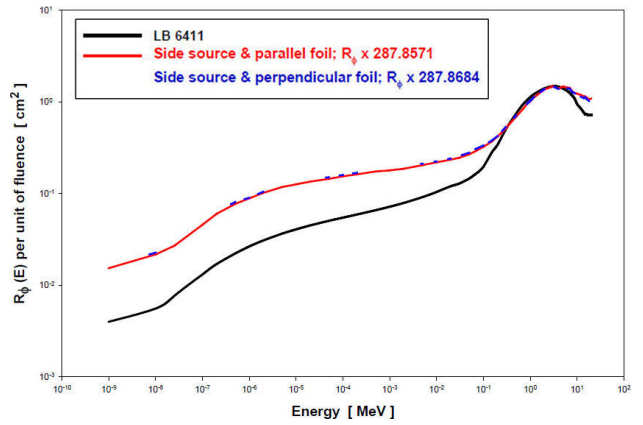FIGURE 2. Activation response functions.



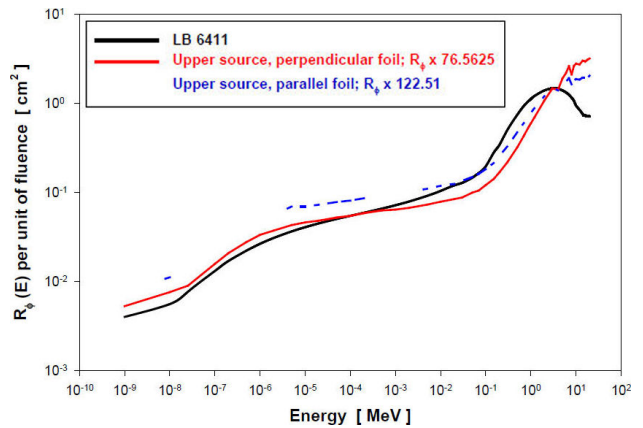FIGURE 3. Response of neutron fluence for the side source.



FIGURE 4. Response of neutron fluence for the upper source.

irradiation geometry the maximum of the response is reached for 3 MeV neutrons. For both irradiation geometries the response has the same shape and the position of the foil has no influence in the response, however the efficiency is larger when the source is above the cylinder.

In Fig. 3 are shown the fluence response of the neutron area monitor Berthold LB6411 [9] and the fluence responses of the passive area monitor with the lateral source. In order to compare the response to 3 MeV neutrons of the passive monitor area was normalized to the response of the LB 6411.

It can be noticed that the fluence responses' shape are alike, but the passive monitor area has larger efficiency for epithermal and thermal neutrons.

In Fig. 4 the fluence responses of the passive monitor area with the upper source, with both foil positions are shown. For these case shapes are similar. The passive monitor shows larger fluence response for neutrons above 3 MeV.

## 4. Conclusions

The ambient dose equivalent and the neutron fluence responses of a cylindrical neutron area monitor were calculated. The neutron area monitor has a passive thermal neutron detector made of a gold foil. For H*(10) the responses are independent of foil orientations with respect to neutron

source. The shape of the fluence response is similar to the response of the monitor LB 6411. The fluence response to the upper source is larger for neutrons from thermal to 3 MeV. When the lateral source is used the fluence response is alike the LB 6411 monitor having larger efficiency for neutrons above 3 MeV. This passive monitor can be used in intense, mixed and pulsed radiation fields, like those reported in radiotherapy vault rooms with linear accelerators.

## Ackknowledments

1. S.A. Martinez-Ovalle, R. Barquero, J.M. Gomez-Ros, M. Lallena, M., *Radiat Prot Dosim*, **147** (2011) 498.

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

3. H.R. Vega-Carrillo, B. Hernández-Almaraz, A. Ortiz-Hernández, *J. Radioanal. Nucl. Chem.*, **283** (2010) 261.

4. R.M. Howell, S.F. Kry, E. Burgett, N.E. Hertel, D.S. Followill, *Med. Phys.*, **36** (2009) 4027.

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

6. J. Benites-Rengifo, H.R. Vega-Carrillo, V.M. Hernández-Dávila, T. Rivera-Montalvo, R. Mondragón, *Procc. Am. Inst. Phys.*, **1310** (2010) 44.

7. R. Barquero, R. Méndez, H.R. Vega-Carrillo, M.P. Iñiguez, T.M. Edwards, *Health Phys.*, **88** (2005) 48

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

9. B. Burgkhardt, G. Fieg, A. Klett, A. Plewnia, B.R.L. Siebert, *Radiat. Prot Dosim.*, **70** (1997) 361.