

## Passive neutron area monitor with TLD pairs

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The response of a passive neutron area monitor with pairs of thermoluminescent dosimeters has been calculated using the Monte Carlo code MCNP5. The response was calculated for one TLD 600 located at the center of a polyethylene moderator. The response was calculated for 47 monoenergetic neutron sources ranging from 1E(-9) to 20 MeV. Response was calculated using two irradiation geometries, one with an upper source and another with a lateral source. For both irradiation schemes the response was calculated with the TLD in two positions, one parallel to the source and another perpendicular to the source. The advantage of this passive neutron monitor area is that can be used in locations with intense, pulsed and mixed radiation fields like those in radiotherapy vault rooms with linear accelerators.

*Keywords:* Neutron; ambient dose equivalent; area monitor.

La respuesta de un monitor de área pasivo para neutrones con pares de dosímetros termoluminiscentes TLDs ha sido calculada mediante métodos Montecarlo con el código MCNP5. La respuesta fue calculada para un TLD 600 localizado en el centro del moderador cilíndrico de polietileno. La respuesta se calculó para 47 fuentes monoenergéticas de neutrones con energías de 1E(-9) a 20 MeV. La respuesta se calculó para dos geometrías de irradiación, una con una fuente superior y la otra con una fuente lateral, para ambas geometrías la respuesta se obtuvo con el TLD en dos posiciones respecto a la fuente, una perpendicular y la otra paralela. La ventaja del monitor pasivo es que puede ser usado en instalaciones con campos de radiación intensos, pulsados y mixtos como los que se producen en los bunkers de radioterapia con aceleradores lineales.

*Descriptores:* Neutrón, dosis equivalente ambiental, monitor de área.

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### 1. Introduction

Natural neutron radiation in the environment has two sources, one comes from outside the Earth and another is in the Earth crust. In the upper atmosphere constantly are produced nuclear reactions between fast primary galactic and solar high-energy particles (Cosmic rays) and the nuclei in the atmosphere. From this interactions are produced secondary electromagnetic, mesonic and nucleonic cosmic-ray cascades. Neutrons and protons are the components of the nucleonic cascades that reach the ground [1]. The neutron fluence, produced by galactic cosmic rays, on the earth surface depends on geographical latitude and is weakly modulated by the solar activity while the fluence, produced by solar cosmic rays, are seen during intense solar flares [2]. Neutrons are also produced in the Earth crust in decays and nuclear reactions occurring in nuclei in rocks and soils. All these neutrons contributes to the dose received by living beings.

Due to its lack of electric charge the measurement of neutrons is not a trivial task, and the determination of neutron dose has been a problem for many years [3,4]. One might define in two major groups the devices used to determine the neutron dose, those that use active detectors and those using passive detectors.

The advantages of devices based upon active detectors are that the measurements are obtained in actual time without the need of process the readouts. On the other hand the disad-

vantage is the need of a voltage source; therefore it cannot be used in locations where neutron intensity is very low or in remote locations where it is needed to do measurements for long time [4]. Another drawback is that cannot be used in pulsed, mixed and intense radiation fields as those presented in linear accelerators and cyclotrons for PET in hospitals [5], high-energy accelerators or in hot spots inside nuclear facilities. To overcome those drawbacks neutrons dosimeters based on passive detectors are used [5,6].

Passive neutron monitors do not require electronics or power supply, incident radiation induces changes in the passive detector that depends upon incident radiation features. Later the induced changes are measured. Pairs of thermoluminescent dosimeters [7,8], activation foils [9], bubble detectors [10], and track detectors [11] have been used for long time.

To determine the dose is desirable to measure the neutron spectrum and with the proper neutron fluence-to-dose conversion coefficients the dose can be determined using equation (1) [12].

$$\Delta = \int_{E_{low}}^{E_{up}} \Phi_E(E) \delta_{\Phi}(E) dE \quad (1)$$

Here,  $\Delta$  is the desired dosimetric quantity,  $\Phi_E(E)$  is the neutron spectrum, and  $\delta_{\Phi}(E)$  is the dose-to-fluence conversion coefficients. The range of both,  $\Phi_E(E)$  and  $\delta(E)$ , goes from  $E_{low}$  to  $E_{up}$ .

Measuring the neutron spectrum is not easy, a neutron spectrometer and an unfolding procedure are required, thus the common practice is to use a neutron area monitor or a remmeter, however those commercially available have an active detector and cannot be used in areas where background neutrons are measured neither in facilities with intense, mixed and pulsed radiation; in such cases a neutron monitor based on a passive neutron detector is preferable.

The aim of this work was to calculate the response functions of a neutron area monitor with a passive detector consisted in pairs of thermoluminescent dosimeters.

## 2. Materials and Methods

The passive neutron monitor area has two parts, the moderator and the neutron detector. Moderator is 20.5 Ø × 20.5 cm<sup>2</sup> polyethylene cylinder with a density of 0.94 g/cm<sup>3</sup>. It has two sections, as shown in figure 1.

Part 1 is a plug, when is fully inserted in the part 2 leaves the thermal neutron detector at the centre. The thermal neutron detector is 4 pairs of thermoluminescent dosimeters of TLD600 and TLD700, each TLD is located in a fixed position inside an acrylic box as it is shown in figure 2.

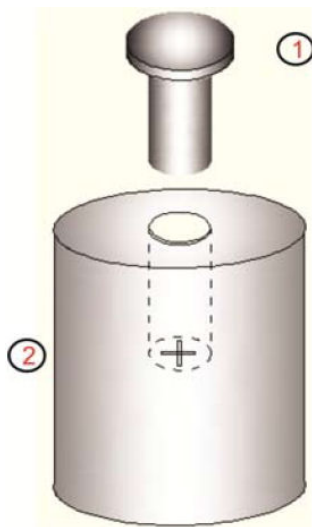


FIGURE 1. Passive neutron area monitor.

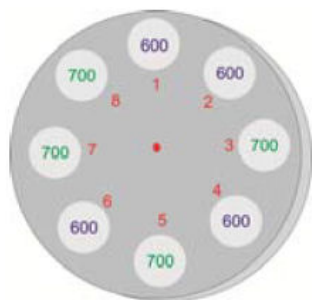


FIGURE 2. TLDs' holder.

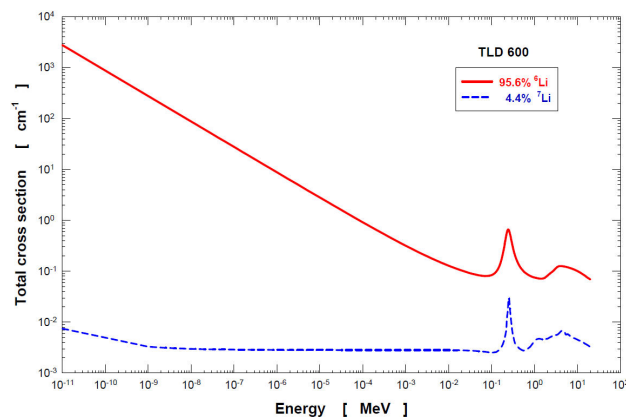


FIGURE 3. Total cross sections of lithium isotopes on TLD600.

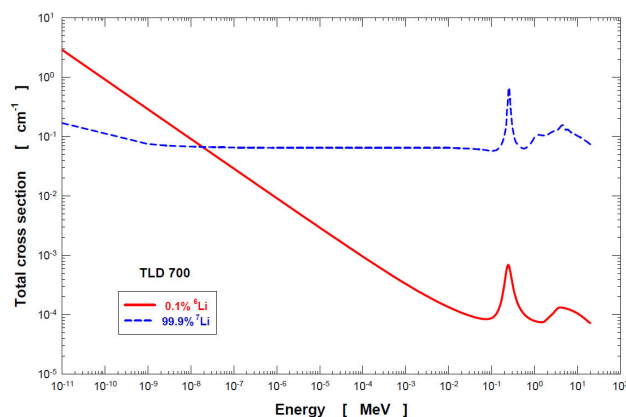


FIGURE 4. Total cross sections of lithium isotopes on TLD700.

TLDs are ribbon type 0.3175 × 0.3175 × 0.0889 cm<sup>3</sup>. TLD600 contains 95.6% of <sup>6</sup>Li and 4.4% of <sup>7</sup>Li, the TLD600's total cross section for neutrons is shown in figure 3 [13].

On the other hand TLD700 is 0.1% of <sup>6</sup>Li and 99.9% of <sup>7</sup>Li. The total cross section of TLD700 is shown in figure 4 [13].

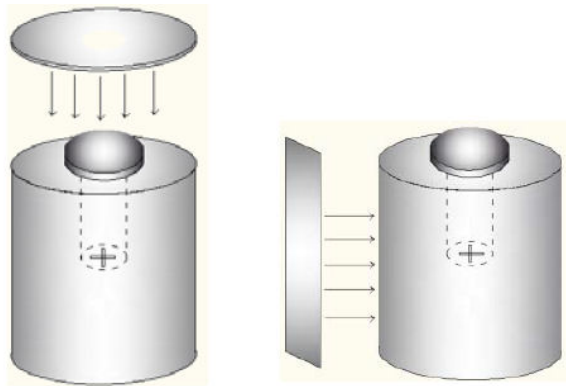
Both TLDs have approximately the same density and effective atomic number, having roughly the same response to gamma-rays. By comparing the cross sections shown in figures 3 and 4 it can be noticed that the response to thermal neutrons of TLD600 is larger than TLD700 response.

When both TLDs are exposed in a neutron and gamma-ray radiation field the response to neutrons,  $R_n$ , is obtained by equation (2).

$$R_n = R_{600}^{n+\gamma} - k R_{700}^{n+\gamma} \quad (2)$$

In equation (2)  $R_{600}^{n+\gamma}$  and  $R_{700}^{n+\gamma}$  are the response to neutrons and gammas of TLD600 and TLD700 respectively, k is an empirical correction factor accounting the difference in the response to gamma-rays between TLD600 and TLD700 [5,7].

Passive neutron monitor area with TLDs, NM/TLDs, response was calculated with Monte Carlo method using the MCNP5 code [14]. For energy, the amount of histories was



(a).- Upper source (b).- Lateral source

FIGURE 5. Irradiation conditions.

large enough to have a Monte Carlo uncertainty below to 3%. The response was calculated using two irradiation geometries, one with a disk source on the top of the NM/TLDs and another with a lateral square source, both geometries are shown in figure 5.

For each irradiation condition the response was calculated with the thermal neutron detector in two different positions, one parallel to the source and another perpendicular to the source. In the calculations 47 monoenergetic neutron sources, ranging from 1E(-9) to 20 MeV were used [15].

The response functions were calculated in terms of the ambient dose equivalent,  $H^*(10)$ , using the ICRP74 conversion coefficients,  $h^*(10)$ , [15] as is shown in equation (3).

$$R_{H^*(10)}(E) = \int_{\forall E} \Phi_E(E) h^*(10)(E) dE \quad (3)$$

### 3. Results and discussion

In figure 6 is shown the NM/TLD's ambient dose equivalent response,  $R_{H^*(10)}$ , when it is irradiated with an upper source with the TLD perpendicular and parallel to the source.

It can be noticed that below approximately 1 MeV both responses are the same. Above 1 MeV there are small differences in the responses probable due to the amount of

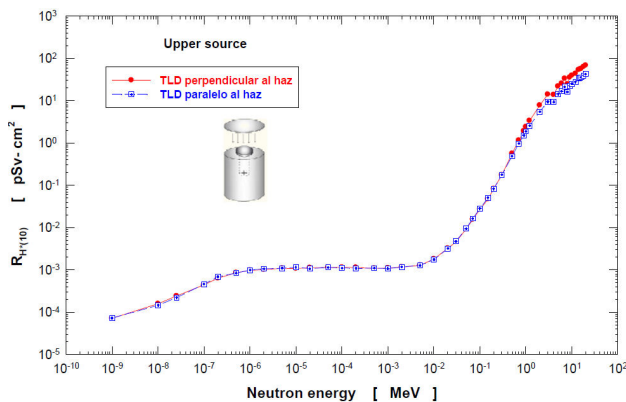


FIGURE 6.  $R_{H^*(10)}$  for the two positions of the TLD using an upper source.

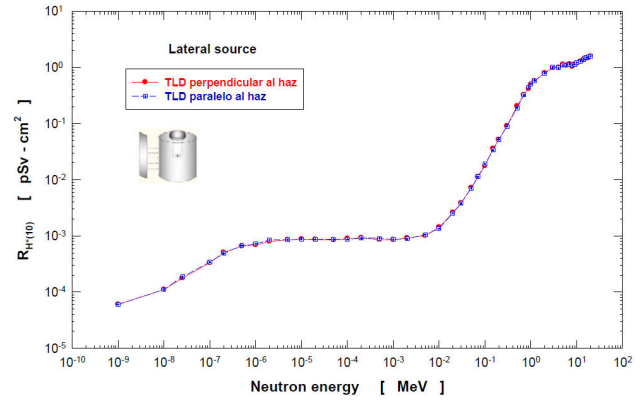


FIGURE 7.  $R_{H^*(10)}$  for the two positions of the TLD using a lateral source.

polyethylene between the source and the TLD, which increase the neutron moderation.

In figure 7 is shown the  $R_{H^*(10)}$  of the neutron area monitor when it is irradiated with a side source for both TLD positions, perpendicular and parallel to the source.

It can be noticed that in this case both responses are the same. By comparing the NM/TLD Ambient dose equivalent response function with those reported for the neutron area monitor Berthold LB6411 [16] and the Leake [17], have the same shapes for thermal up to approximately 1 MeV. For energies larger than 1 MeV the response of commercially available monitors tend to decrease while the NM/TLD responses tend to increase, this difference is probable due to the size and shape of moderator.

### 4. Conclusions

Using Monte Carlo method the response of a passive neutron area monitor has been calculated. The monitor has a thermal neutron detector made of TLD600 and TLD700 pairs, and the response functions were estimated for a single TLD600 located, at two positions at the center of cylindrical moderator. Also, the response was calculated using two irradiation geometries: lateral and upper.

For upper irradiation the monitor area  $H^*(10)$  response functions are alike for neutrons below 1 MeV, being slightly larger above 1 MeV when TLD is perpendicular to incident neutrons.

For lateral source the  $R_{H^*(10)}$  functions are independent of TLD orientation with respect to incident neutrons.

From thermal to 3 MeV calculated responses have the same shape as responses of commercial available neutron area monitors as the Berthold LB6411 and Leake [16,17].

Due to the NM/TLD uses a passive neutron detector it can be used also in high and pulsed mixed radiation fields and in locations where neutron fluence is low and long-time measurements are needed.

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1. T.J. Dunai, *Cosmogenic Nuclides: Principles, concepts and applications in the Earth surface sciences*. (Cambridge University Press, Cambridge UK. 2010). pp. 3-6.
  2. S. Pszona, *Neutrons in natural environment*. (Proceedings of IRPA Regional Symposium, 1997) pp. 157-160.
  3. J.W. Leake, *Nucl. Instrum. Meth.*, **45** (1966) 151.
  4. H.R. Vega-Carrillo, E. Manzanares, *Nucl. Instrum. Meth. Phys. Res. A*, **524** (2004) 146.
  5. H.R. Vega-Carrillo, *Nucl. Instrum. Meth. Phys. Res. A*, **463** (2001) 375.
  6. J.M. Gómez-Ros, R. Bedogni, M. Moraleda, A. Romero, A. Delgado, A. Esposito, *Radiat. Meas.* **45** (2010) 1220.
  7. H.R. Vega-Carrillo, *Radiat. Meas.* **35** (2002) 251.
  8. S.P. Tripathy, A.K. Bakshi, V. Sathian, S.M. Tripathi, H.R. Vega-Carrillo, M. Nandy, P.K. Sarkar, D.N. Sharma, *Nucl. Instrum. Meth. Phys., Res. A*, **598** (2009) 556.
  9. R. Bedogni, A. Esposito, A. Gentile, M. Angelone, G. Gualdrini, *Radiat. Meas.*, **43** (2008) 1104.
  10. A. Zanini, E. Durisi, F. Fasolo, L. Visca, C. Ongaro, U. Nastasi, K.W. Burn, J.R.M. Annand, *Radiat. Prot. Dosim.* **110** (2004) 157.
  11. M. Kralik, K. Turek, V. Vondracek, *Radiat. Prot. Dosim.* **132** (2008) 13.
  12. H.R. Vega-Carrillo, V.M. Hernández-Dávila, E. Manzanares-Acuña, E. Gallego, A. Lorente, M.P. Iñiguez, *Radiat. Prot. Dosim.* **126** (2007) 408.
  13. NNDC. [online]. Evaluated Nuclear Data File (ENDF) Retrieval & Plotting. <http://www.nndc.bnl.gov/sigma/index.jsp?as=10&lib=endfb7.0&ns=10> National Nuclear Data Center, Brookhaven National Laboratory. [Reviewed on Nov. 2010].
  14. 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)
  15. ICRP 74, *Annals of the ICRP* **26** (1996) 199.
  16. Berthold. [online]. LB 6411-Pb Neutron Dose Rate Probe for High Energy Neutrons. <http://www.berthold.com/ww/en/pub/strahlenschutz/produkte/rppldose/lb.6411.6411.pb.cfm>. (2008). Berthold Technologies GMBH & Co. [Reviewed on Dec 2010].
  17. J.W. Leake, T. Lowe, R.S. Mason, G. White, *Nucl Instrum Meth. Phys. Res. A*, **613** (2010) 112.