Passive neutron area monitor with CR39

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ABSTRACT

Background: In high-intensity, mixed and pulsed neutron fields the use of spectrometers or area monitors with active detectors is useless; in these conditions neutron measuring devices must have a passive detector. Here a passive neutron area monitor with CR39 track detector was designed and the response was calculated. **Materials and Methods:** The response of a passive neutron area monitor with CR39 track detector has been calculated with the MCNPX code. To increase the detection efficiency a ^{10}B converter was included. The response was calculated using 47 monoenergetic neutron sources. **Results:** A passive neutron area monitor using a CR39 with ^{10}B converter was designed where fluence and H*(10) responses were calculated. **Conclusion:** The shape of the responses is similar to responses reported for neutron monitors with active detectors.

Keywords: Neutron dosimetry, passive detector, CR-39, Monte Carlo, response.

INTRODUCTION

The measurement of the neutron-related quantities like, spectrum, fluence or dose around nuclear facilities is of increased interest [1]. However neutron measurement is not an easy task, particularly behind thick shielding, where neutron population is very low and long time measurements are required to have a good statistics [2]. In such conditions, the use of spectrometers, rem-meters, neutron survey or neutron area monitors with active detectors is limited by the need of a constant power supply. The same problem occurs in underground laboratories where is required to measure the neutron fluence induced by natural radioactivity and cosmic muons [3].

Neutron measurement is also difficult in sites where the radiation field is intense and mixed with photons, like in "hot" areas around nuclear reactor facilities or in particle research accelerators, where radiation field is also pulsed [4, 5]. In pulsed, mixed and intense radiation fields the operation of devices with active detectors are disturbed by dead time effects and pulse pileup. In addition, the presence of radiofrequency fields could affect the circuitry of neutron monitors [5-7].

To have a good estimation of neutron dose, Δ, it is advisable to measure the neutron spectrum, $\Phi_E(E)$, and with the proper fluence-to-dose conversion coefficients, $\delta_\Phi(E)$, to estimate the dose using equation 1.

$$\Delta = \int_{E_{min}}^{E_{max}} \delta_\Phi(E) \, \Phi_E(E) \, dE \qquad (1)$$

Neutron spectrum measurement is not a trivial task, thus in practical situations a neutron area monitor o neutron survey instrument is used. These devices have an active thermal neutron detector inserted inside a moderator.

To overcome problems associated with very low neutron population or intense radiation fields passive detectors are used such as Bubble

detectors [8] or TLD pairs [9, 10], activation foils [4, 11-13] and track detectors [14, 15] as thermal neutron detectors in Bonner sphere spectrometers however, the weight, time consuming to perform the measurements, poor resolution, and the need of unfolding procedure are some drawbacks pointed out for multi-sphere spectrometer [16]. Also, track detectors have been used as fast neutron dosimeter [17].

Solid state nuclear track detectors, SSNTD, are commonly used in wide applications of fundamental and applied physics and technology to register charged particles [18] and in neutron dosimetry [15, 19].

Commercially available single-moderating type monitors with active detector, are used to survey the neutron dose. Mostly are based upon the work of Anderson and Braun [20] and Leake [21]. Variations of these devices using a passive detector have been developed [22-24].

An inexpensive passive neutron area monitor, using a CR39 track detector, was designed. The aim of this work is to calculate the monitor´s response using Monte Carlo methods.

MATERIALS AND METHODS

In this work, a passive neutron detector based on CR39 Poly-Allyl Diglycol Carbonate, PADC, with features obtained from Page Mouldings Ltd, UK, was used. It has been pointed out that a better performance in the dosimetry using solid nuclear track detectors can be obtained by adding an extra foil or radiator [15], thus to increase the neutron detection efficiency the CR39 was coupled to a ^{10}B converter, with features provided by DOSIRAD Laboratory (Pierrelatte, France).

This detector was in the centre of a polyethylene moderator 20.25 Ø × 20.25 cm^2 having the passive neutron area monitor. With this array thermal neutrons are detected through (n, α) reactions occurring in ^{10}B, while epithermal and fast neutrons are detected through n-p reactions.

Using the MCNPX code [25] the response was calculated for 47 monoenergetic neutron sources ranging from 10^{-9} up to 20 MeV. Neutron detector was modeled as three cells: the 0.5 × 1.7 × 0.1 cm^3 CR39, the converter's support was modeled as polyethylene terephthalate, PET; 0.5 × 1.7 × 0.01 cm^3, and the converter modeled as 0.5 × 1.7 × 0.0035 cm^3 100% ^{10}B, this was in contact with the sensitive face of CR39. The detector was located at the centre of the polyethylene moderator, and the source term was modeled as a 20.25 × 20.25 cm^2 square producing a broad parallel neutron beam colliding against the moderator surface. In figure 1 is shown the passive neutron area model.
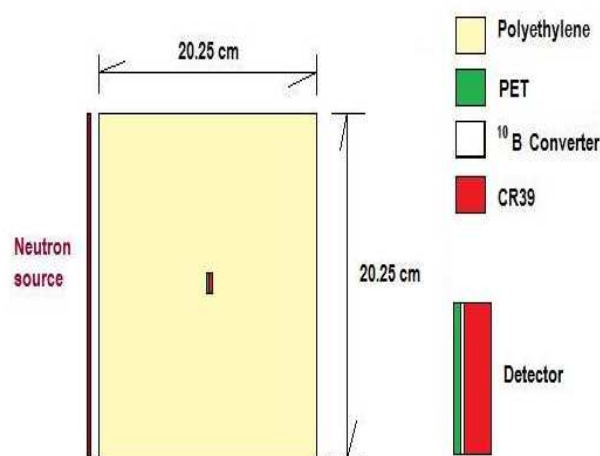

Figure 1. Model used in the calculations.

For each neutron source the amount of histories was large enough to reach an uncertainty less than 3%, the total fluence in the PET, the ^{10}B converter and in the CR39, as well as the total amount of (n, α) reactions occurring in the ^{10}B converter. Importance values were assigned to the cells for variance reduction, no energy cutoffs were included. In the calculations, the ENDF/B-VI cross section library was used; in order to include the moderator effect on the low energy neutrons the S(α, β) treatment was included.

The neutron fluence was calculated for each neutron emitted by the source in each cell using the f4 tally. The amount of ^{10}B(n, α)^{7}Li reactions occurring in the ^{10}B converter was calculated using tally f4 and reaction 107. The ambient dose equivalent response was calculated using

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equation 2.

$$R_{H*(10)}(E) = \int_{10^{-9}}^{20} h^*(10)(E) \; \Phi_E(E) \; dE \qquad (2)$$

Here, h*(10)(E) are the fluence-to-ambient dose equivalent conversion coefficients from ICRP 74 [26], $\phi_E(E)$ is the neutron fluence in the ^{10}B converter cell. The relative response was compared against the h*(10)(E).

Using Monte Carlo methods the responses of a passive neutron area monitor has been calculated. The neutron detector is based in a CR39 track detector with a ^{10}B converter. Main advantages of passive devices is that do not requires a power supply during neutron monitoring, on the other hand the disadvantage is that it does not delivers the neutron dose information in real time.

In figure 2 is shown the fluence response in PET, ^{10}B converter and CR39; following the same trend responses increase as the neutron energy raises.

In figure 3 are the (n, α) reactions occurring in the ^{10}B converter, these secondary α-particles produced in the converter induce etchable damage in the CR39 track detector [16]. The larger amount of reactions are produced by 2 MeV neutrons, meaning that the moderator is large enough to moderate 2 MeV neutrons reaching the ^{10}B converter with the energy to produce the (n, α)

reaction. The lowest (n, α) response is for thermal neutrons; here the fast-to-thermal response ratio is roughly 10.2 thus this device can be used in heavy shielded facilities where the thermal-to-fast neutron fluence has been reported as 7.3 [27].

In figure 4 are the area monitor relative response to the ambient dose equivalent and the ambient dose equivalent coefficients from ICRP 74. Therefore the passive neutron area monitor can be used to measure the ambient dose equivalent is locations where radiation field is mixed, intense and pulsed [5, 13] where knowledge of dose is critical in the shielding design [27]. Due to the lack of power supply the passive neutron area monitor is also suitable to measure the neutron dose behind thick shielding or in underground laboratories where neutron population is very low and long time measurements are required to achieve good counting statistics [3].

The shape of relative response is close to the response reported in the literature [22-24]. Response determined by Agosteo *et al.* [22] have better approach to the h*(10) that the response in figure 3; the probable explanation is because they use a 33.2 cm-diameter polyethylene sphere with an inner 0.6 cm-thick, 5.5 cm-radius Pb shell. The ideal response of a neutron area monitor should be the same as the fluence-to-ambient dose conversion coefficients, in the aim
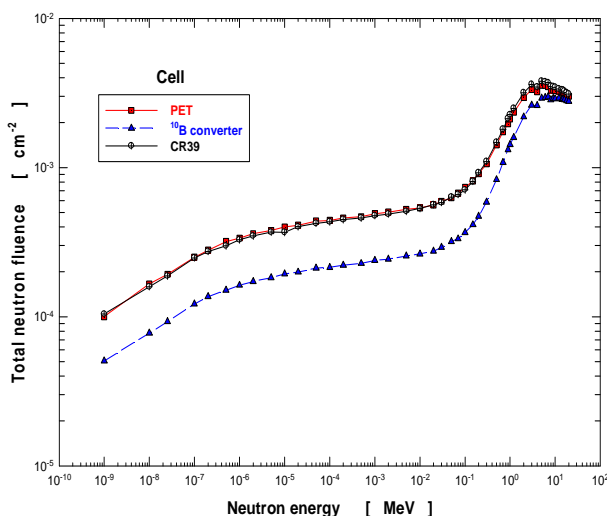
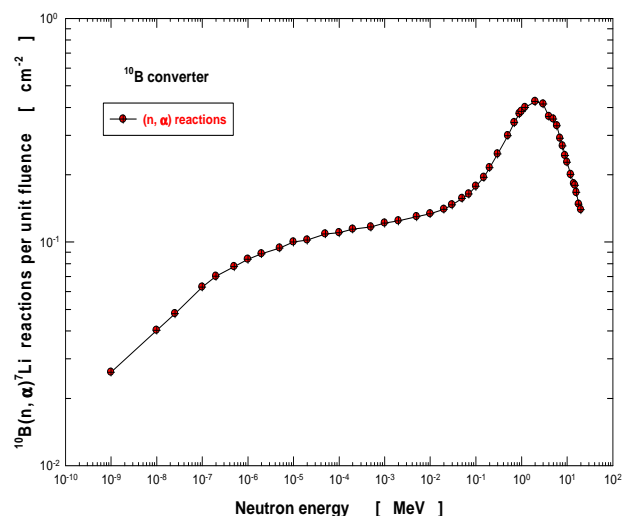**Figure 2.** PET, ^{10}B converter, and CR39 fluence responses.

Figure 3. ^{10}B converter (n, α) response.

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to fulfill such response neutron monitors with active detectors use a neutron absorber around the thermal neutron detector. As shown in figure 4 the passive-neutron-area-monitor's response have the trend of h*(10), this response could be improved adding a neutron absorber around the CR39 detector.
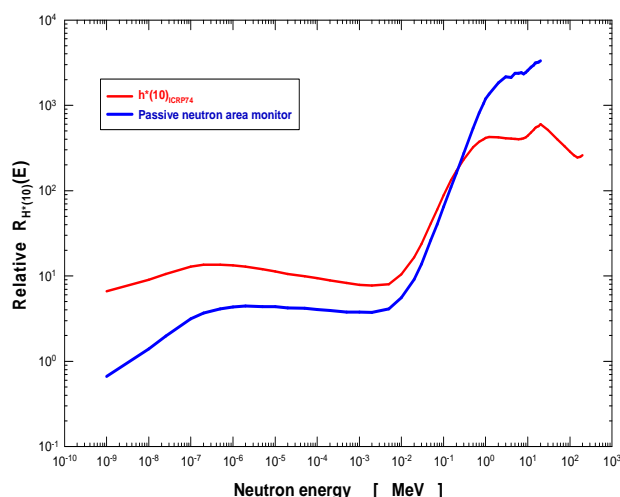

Figure 4. Passive neutron area monitor relative response compared to the h*(10).

CONCLUSION

The fluence, $^{10}B(n, \alpha)^7Li$ reactions and H*(10) responses of a passive neutron area monitor have been calculated using MCNPX code. Fluence and ambient dose equivalent response shapes are alike to those reported in literature, however despite the response follows the proper trend the design could be improved adding a neutron absorber.

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