MCNP simulation of the incident and albedo neutron response of the IRD albedo neutron dosemeter for ^{241}Am–Be moderated sources

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Abstract: The IRD TLD albedo dosemeter measures both incident and albedo neutron component. The incident to albedo ratio is used to take into account the energy dependence of its response. In this paper, the behavior of the IRD albedo dosemeter response as a function of the incident to albedo ratio for ^{241}Am–Be sources was simulated to improve its algorithm. The simulation was performed in MCNPX transport code and presents a good agreement with experimental measurements. The results obtained in this work are very useful to improve the accuracy of the IRD albedo dosemeter at real neutron workplace.

Keywords: albedo neutron dosemeter, Monte Carlo simulation, calibration.

1. INTRODUCTION

Job-related neutron fields are always due not only to the primary beam of equipment and practices involving neutrons, but also to moderated and scattered neutrons. In Brazil, most activities with possible neutron irradiation are due to the use of ^{241}Am–Be sources. However, the workers are seldom exposed to bare sources. Normally, the occupational neutron fields are due to moderated ^{241}Am–Be, besides scattering from the workplace. The moderation and the scattering occur through interaction of the neutron emitted by the source and all materials present in the room, around the source and the worker. Hydrogenous materials are good neutron moderators. In the moderation process, the mean energy of the spectrum decreases and the fluence of thermal neutrons increases [1].

All type of individual neutron dosemeter has a high energy response variation. The Divisão de Dosimetria (DIDOS) of the Instituto de Radioproteção e Dosimetria (IRD) runs a monthly neutron individual monitoring service since 1983. Nowadays, DIDOS/IRD uses a TLD albedo developed by Martins et al. [2,3]. This dosemeter measures both incident and albedo neutron component and it is calibrated to personal dose equivalent at 10 mm depth, $H_P(10)$. The ratio of the incident to albedo component (*i/a*) is used in its algorithm to get an energy correction factor (*ECF*) for the albedo neutron reading calibrated for a reference neutron beam. It takes into account the energy dependence of its response. For different degrees of moderation of the same primary source, different values of *ECF* have to be used in the albedo algorithm for more accurate neutron dose evaluation. Nevertheless, the plot of this correlation function is very difficult because it demands an enormous set of irradiation in standardized neutron fields, which are not available. Thus, simulation is an important tool for the development of more realistic energy correction calibration curve.

This paper aims to simulate the behavior of the ECF values as a function of the ratio *i/a* for the IRD albedo neutron dosemeter irradiated with moderated ^{241}Am–Be sources. The simulation is validated using some experimental values of ECF for different *i/a* values.

2. MATERIALS AND METHODS

2.1. The IRD TLD albedo dosemeter

The IRD TLD albedo neutron dosemeter used in this work is shown in figure 1. It is worn in an adjustable belt and fixed on the human body. The TLD600® is sensitive to neutron and photon and TLD700® is sensitive only to photon. The subtraction of the reading of the TLD700 from the readings of the TLD600 provides the neutron reading. One pair of TLD, which is in front of the boron-loaded shield, measures the incident thermal neutron component (*i*). In addition, the other pair of TLD measures the neutron backscattering from the human body, i.e. the albedo component (*a*), and is employed for the determination of the $H_P(10)$.

The neutron calibration factor (*NCF)* for the reference condition is determined according to equation 1:

$$NCF = \frac{H_P(10)_{reference}}{D_{a\,TLD600} - D_{a\,TLD700}} \quad (1)$$

where:

$D_{a\,TLD600}$ and $D_{a\,TLD700}$ are the measured dose at the albedo position, for TLD600 and TLD700 respectively, normalized to free air kerma (mGy) of ^{137}Cs;
$H_P(10)$ is the reference value of neutron personal dose equivalent at the point of test.

In this paper, *NCF* is evaluated for a standardized neutron field of bare ^{241}Am–Be source. *ECF* is calculated by equation 2:

$$ECF(i\,/\,a) = \frac{L_{moderated}}{H_P(10)_{reference}} \quad (2)$$

where:

$L_{moderated}$ is the $H_P(10)$ neutron value reading at a moderated ^{241}Am–Be neutron field using the reference NCF value.

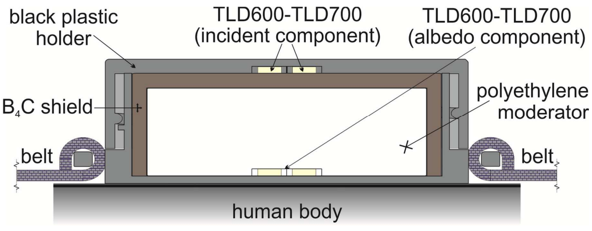

Figure 1: IRD albedo dosemeter design.

Thus, the actual neutron calibration factor to be used in the algorithm for any measurement will be calculated as the product of *NCF* and *ECF*. This factor should be applied in the albedo neutron component reading, normalized to free air kerma of ^{137}Cs.

2.2. Monte Carlo methodology

2.2.1 Modelling of ^{241}Am–Be moderated spectra

The simulation was made in vacuum, using a single dosemeter located on the center of the front face of an ISO water slab phantom. The ^{241}Am–Be ISO standard neutron spectrum presented in the table A.4 of the annex A of the ISO 8529-1 [4], described as a 30 cm × 30 cm plane parallel beam, in normal incidence to the front face of the phantom is used as the source.

In order to generate the moderated ^{241}Am–Be neutron spectra, a moderator block with dimensions of 30 cm x 30 cm and variable thickness (*x*), was inserted between the source and the dosemeter, as shown in figure 2. The moderator materials were water, with thicknesses of 1.0, 2.0, 4.0 and 40.0 cm and paraffin, with thicknesses of 0.2, 0.5, 1.0, 2.0, 4.0, 6.0, 10.0, 20.0 and 50.0 cm.

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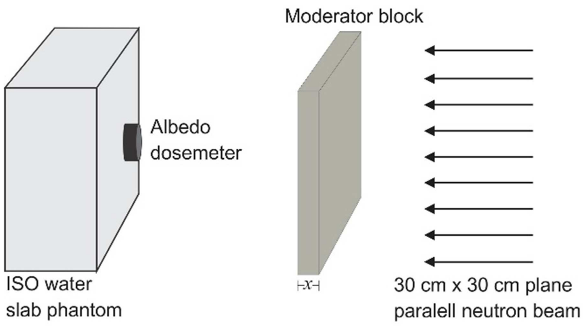

Figure 2: Simulated irradiation geometry

All spectra simulations were performed with MCNPX Monte Carlo transporting code. The figure 3 shows some of these spectra.

2.2.2. Modelling of IRD albedo dosemeter

The MCNPX modelling of the IRD albedo dosemeter readings used in this work is the same used by Freitas et al [5]. The thermoluminescent neutron responses of the TLD600 and TLD700 at albedo and incident positions were estimated by the neutron absorbed dose on them. Photons were also included in the particle mode card, in order to take in account the neutron-induced photons kerma. The number of histories was chosen to ensure that the statistical errors in all tallies were about 5%. The ratio *i/a* was calculated for each simulated spectra and is independent of neutron calibration.

The neutron fluence at the point of test was calculated using MCNPX tally F4. The value of the neutron $H_P(10)$ was obtained multiplying the neutron fluence at the point of test (without dosemeter and phantom) by the appropriate fluence to personal dose equivalent conversion coefficient, $h_{P\Phi}(10;E;0°)$ for each neutron energy, *E*, as recommended in ISO 12789-1 standard [6]. *ECF* for bare ^{241}Am–Be is set to unit value.

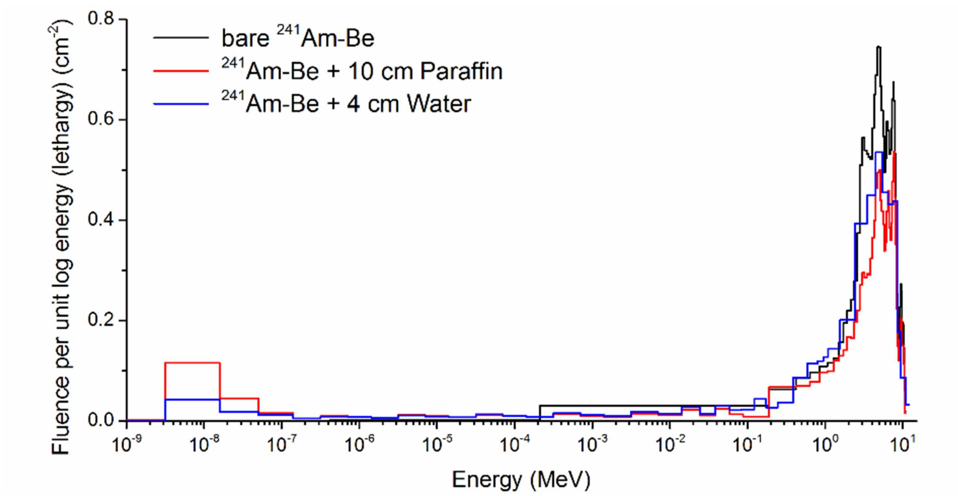

Figure 3: Simulated moderated ^{241}Am–Be neutron spectra compared to bare one.

2.2.3. Validation of the simulation

Experimental measurements were used in order to validate the behavior of the simulated curve of *ECF* values versus *i/a*. For this, several IRD albedo dosemeters were evaluated after irradiation with all the ^{241}Am–Be neutron fields available at the Neutron Laboratory of the Brazilian National Metrology Laboratory: bare; and moderated with 4 cm of paraffin, 4 cm of silicone, thermalized and behind shadow cone.

3. RESULTS

Figure 4 shows the simulated *ECF* values versus the ratio *i/a* for the thirteen simulated neutron spectra and the four experimental ones. In the same graph, a fit of *ECF* versus *i/a* is also plotted and is done by equation 3:

$$ECF(i/a) = 0.38 - 0.09 \times ln[(i/a) - 0.024] \quad (3)$$

The coefficient of determination (R^2) value of the fit adjustment is 0.92. In the figure 4, it can be seen also that the experimental points, considering their uncertainties, are covered by the fitted curve, validating the simulation.

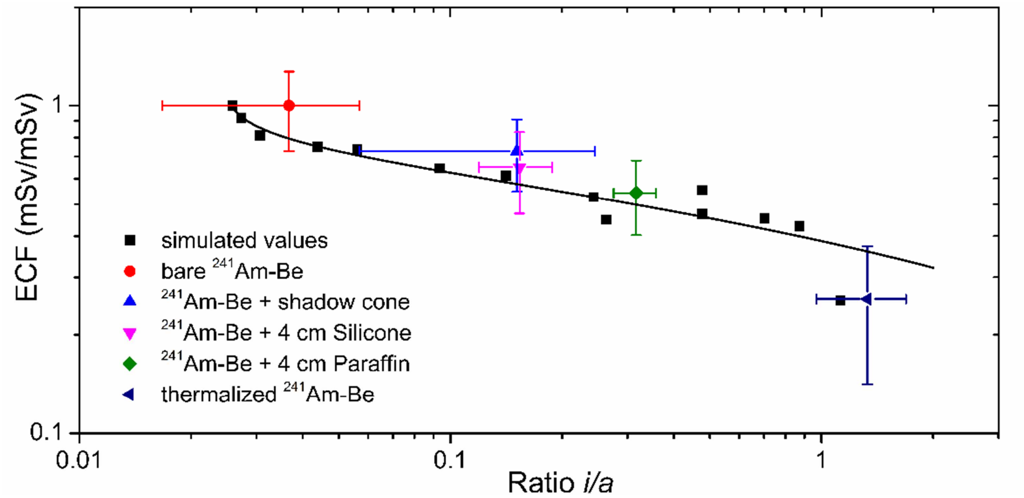

Figure 4: *ECF* versus the ratio *i/a*.

4. CONCLUSION

The results obtained in this work are very useful to the understanding of the response of the IRD albedo dosemeter. The correlation curve between the ratio *i/a* and the ECF can improve the results of the measurements made with the IRD albedo neutron dosemeter in its routine service.

The same methodology can be applied to estimate neutron ECF for any other stray neutron field. It can also be used to make some improvements in the albedo dosemeter, if necessary.

5. ACKNOWLEDGMENT

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6. REFERENCES

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