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BRAZILIAN GAMMA-NEUTRON DOSIMETER: RESPONSE TO ^{241}AMBE AND ^{252}CF NEUTRON SOURCES

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Aiming to improve the monitoring of workers potentially exposed to neutron radiation in Brazil, the IPEN/CNEN-SP in association with PRO-RAD designed and developed a passive individual gamma-neutron mixed field dosimeter calibrated to be used to ^{241}AmBe sources. To verify the dosimetry system response to different neutron spectra, prototypes were irradiated with a ^{252}Cf source and evaluated using the dose calculation algorithm developed to ^{241}AmBe sources.

INTRODUCTION

Neutron dose measurement is a difficult matter, the detectors response usually is highly energy dependent; aiming to improve de neutron dosimetry different neutron detection techniques have been studied, developed and employed. The use of polymeric material detectors, especially the polycarbonates and the CR-39, has been studied to be applied as etched-track detectors in fast neutron dosimetry [1-4] with the advantage of including permanent registration [5-6]. Dosimetry of reflected neutrons from the human body can be made by means of albedo dosimetry techniques, developed by different authors [7-9]. The main advantages of the TL dosimeters are the high (n-γ) discrimination capability and the very small dimension.

In both methods to determine the neutron dose the neutron spectrum must be known and the dose response curves and dose calculation algorithm have to be obtained to the neutron spectrum evaluated. For personal dosimeters, basic physical requirements like the correct dependence of the dosimeter response on energy and incident neutrons angle are required.

Neutron personal monitoring in Brazil is growing up due to the increasing use of neutron sources in industrial and medical applications. Aiming to improve the monitoring of workers potentially exposed to neutron radiation, the IPEN/CNEN-SP, a governmental Research Center, in association with PRO-RAD, a private Monitoring Service, designed and developed a passive individual gamma-neutron mixed field dosimeter firstly calibrated to be used to ^{241}AmBe sources [10].

The dosimeter uses the techniques of Albedo Thermoluminescence Dosimetry (TLAD) to evaluate thermal and intermediated neutron doses contribution and Solid State Nuclear Track Dosimetry (SSNTD) to evaluate fast neutrons dose contribution.

Using the combination of this two techniques it is possible to evaluate the dose and analyse the neutron spectrum.

Previous studies [10-11] shown that this dosimetry system – dosimeter and dose calculation algorithm – is adequate according to ISO/DIS 21909 requirements [12] to ^{241}AmBe sources dosimetry.

Aiming to verify the dosimetry system response to different neutron spectra, to confirm the neutron energy dependent response, prototypes were irradiated with a ^{252}Cf source and evaluated using the dose calculation algorithm developed to ^{241}AmBe sources. The only objective of this study was comparing the obtained responses for both ^{241}AmBe and ^{252}Cf sources and evaluate the errors involved in this case.

MATERIALS AND METHODS

Prototype Description

The dosimeter prototype (Figure 1) consists of a sandwich of three polyethylene plates, with holes to support the TL and track detectors and a cadmium filter, between PMMA support plates.

The sensitive TL materials are two TLD-600/TLD-700 pairs with the cadmium filter between each pair and one SS-1 polycarbonate track detector 1.5 mm thick.

The polycarbonate is a Brazilian commercially available resin, named SS-1, produced with the same

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chemical monomer of Makrofol, $C_{16}H_{14}O_3$. It is offered in plates (165 x 244 x 0.15 cm^3) with both sides protected by a plastic film. Small pieces (3 x 1 cm^2) were cut and selected.

One corner of the sample was signed; the same side of the plate was always evaluated, to obtain reproducible positioning irradiating and evaluating. The detectors were stored at room temperature and ambient light.

Dose Evaluation

The TL detectors pair in the frontal position determines incident thermal neutrons and gamma radiation doses; the second TL pair evaluates albedo neutrons doses and the SS-1 detector estimates fast neutrons doses. The ratio of fast and albedo neutrons responses allows estimating the incidence angle and, then, correcting the fast neutrons dose response.

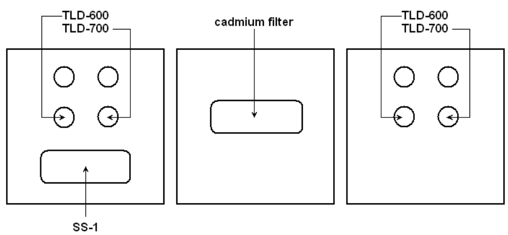

Figure 1. Dosimeter prototype internal view.

Chemical Etching

The chemical etching of the detectors consisted of 3h etching under PEW-40 solution at 75°C. The detectors were dried in air at room temperature.

Track counting procedure

The SS-1 detectors surfaces were visualized through a video camera connected in an optical microscope.

The counting area is defined by 20 x 0.1 mm^2 fields of the detector surface, called bands. The track counting was done visually. The track density is the arithmetic mean of five different bands counting. To minimize the human error the Chauvenet Criterium was used to neglect and substitute bands with high statistical influence on the mean.

Fast Neutron Dose Algorithm

Considering only normal incidence angle the track dosimeter shows a linear dose response in the dose range between 0.5 and 20 mSv and the dose calculation algorithm is a linear equation.

$$\text{Dose} = a.TD + b \qquad (1)$$

where *TD* is the SS-1 track density (tracks/cm^2) and *a* and *b* are, respectively, the angular and the linear coefficients.

The ratio of fast and albedo neutron responses could be considered constant as a function of dose, but decreases as a cosine function with increasing radiation incidence angle [11].

Knowing the incidence angle (θ), a correction factor, equal to the inverse of this angle's cosine, must be applied in the dose calculation algorithm:

$$\text{Dose} = a.TD.\cos^{-1}(\theta) + b \qquad (2)$$

Prototype Irradiation

The dosimeters were positioned on an ISO slab phantom and irradiated using isotropic ^{241}AmBe and ^{252}Cf sources at Neutrons Laboratory of the National Laboratory of Ionizing Radiation Metrology - LN/LNMRI. The prototypes were irradiated with 10 mSv with normal incidence.

The neutron sources were calibrated against a primary standard of $MnSO_4$ and maintain traceability to BIPM. The personal doses equivalent [Hp(10)] were calibrated using the same ISO slab phantom.

Each presented value is the average of five measurements.

RESULTS

The average responses of each detector type to each neutron source are shown in Table 1. The difference of the thermal, albedo and fast neutrons responses are in agreement with the difference between the spectral neutron distributions of the two sources. However the ratio of albedo and thermal neutrons responses are of the same order.

Table 1. Prototypes media responses in arbitrary units.

	^{241}AmBe	^{252}Cf
Thermal neutrons (Nth)	2,8 ± 0,2	4,0 ± 0,3
Albedo neutrons (Na)	11,1 ± 0,5	16,1 ± 0,7
Fast neutrons (Nf)	(2,3 ± 0,4).10^3	(1,0 ± 0,2).10^3
Na / Nth	4,0 ± 0,3	4,0 ± 0,3
Nf / Nth	(2,1 ± 0,4).10^2	(0,6 ± 0,2).10^2

The dose calculation algorithm determined previously to ^{241}AmBe sources (equation 1) failed when used to ^{252}Cf source: the dose was overestimated + 50% to albedo neutrons and underestimated - 65% to fast neutrons.

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Applying the angular correction (equation 2) to prototypes irradiated with ^{252}Cf, supposing that they were irradiated with ^{241}AmBe, the dose was overestimated in 20%.

The observed errors in the neutron dose evaluation are higher than 40% accepted to ISO/DIS 21909 for angular incidence.

CONCLUSION

As expected, the dose calculation algorithm determined earlier is valid only to ^{241}AmBe sources. The requirements of ISO/DIS 21909 can not be satisfied in this case.

To improve this neutron dosimetry system it is necessary to obtain new calibration curves on different neutron spectra and to determine specific dose calculation algorithms, including angular dependent response correction.

The ratios of fast, albedo and thermal neutrons responses could be used as an energy spectrum analyser parameter. It denotes qualitatively the presence of fast and/or thermal neutrons, allowing the choice of better algorithm to be applied on each case.

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