1st International & 28th National Conference on Nuclear Science & Technology 2022 (ICNST22)
Nuclear Science & Technology Research Institute

Film badge as an alternative personal dosimeter for thermal neutrons

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Abstract

In the present work for the first time in Iran performance of film badge as an alternative personal dosimeter for thermal neutrons is investigated by adding a cadmium-lead (Cd-Pb) filter with the same thickness as the tin-lead (Sn-Pb) filter of the badge. Since thermal neutrons are mixed with gamma rays, the dosimeter is irradiated in the ^{60}Co gamma rays standard field of Karaj SSDL as well as the mixed neutron-gamma field of the radiography beamline of Isfahan Miniature Neutron Source Reactor (MNSR) in the personal dose-equivalent range of 0.1 to 10 mSv. Result obtained reveal that film badge simultaneously determines the thermal neutrons and gamma rays dose fractions. The uncertainty of neutron dose-equivalent is 50% which is acceptable in personal dosimetry.

Keywords: Film badge, Thermal neutron, Personal dosimetry

Introduction

Dosimetry of thermal neutrons is important for the personnel working with radiography or neutron activation analysis facilities in the research reactors. Generally, in Iran solid state nuclear track detectors (SSNTDs) and thermoluminescence dosimeters (TLDs) are common tools for personal dosimetry of neutrons [1]. In situations where use of these dosimeters is not feasible, choosing an alternative one becomes important. It is shown that film badge dosimeters that are commonly used for gamma rays, can be used as an alternative for dosimetry of thermal neutrons [2].
Film badge includes a radiographic film embeded in a plastic badge with different filters. The optical density (OD) produced on the film due to ionizing radiation is utilized for dose estimation and is given by Eq. (1):

$$OD = log_{10}\left(\frac{I_0}{I}\right) \qquad (1)$$

in which I_0 and I are the visible light intensities before and after passing the film, respectively, while reading the film by a densitometer. Applying a metalic filter having a high interaction cross-section with thermal neutrons, such as cadmium, enables to measure neutron dose. Thus, Cd-Pb filter has been used for this purpose [2]. Interaction of thermal neutrons with cadmium produces gamma rays for which the related OD is used to determine the dose. Since thermal neutrons are mixed with gamma rays, there would be excess OD under the Cd-Pb filter caused by these rays. Therefore, the Cd-Pb filter must have as similar sensitivity to gamma rays as the Sn-Pb filter of the badge in order to distinguish the OD of thermal neutrons from the total amount in the mixed field. Hence, thickness of the Cd-Pb filter has to be the same as Sn-Pb filter (i.e. 0.7 mm Cd and 0.3 mm Pb). Further, the densities of Cd and Sn are 7.26 g/cm^3 and 8.65 g/cm^3, respectively, resulting in similar attenuation/absorption coefficients for gamma rays. Subject of this work is to study, for the first time in Iran, performance of the film badge for personal dosimetry of thermal neutrons as an alternative to other personal neutron dosimeters.

Materials and methods

First, a Cd-Pb filter was placed between Sn-Pb and aluminum filters in the badge according to Fig. 1. Radiographic films with 3 cm × 4 cm (from FOMA company) were used. Ten dose equivalent values, $H_p(10)$, from 0.1 mSv to 10 mSv were selected. For any dose including the background, three film badges were used to reduce the statistical uncertainty.
In the next step, the dosimeters were irradiated with ^{60}Co gamma rays of the standard field of Karaj SSDL generated by a Picker V9 irradiator. The badges were positioned on a phantom (PMMA walls filled with water) with a dimension of 30 cm × 30 cm × 15 cm. In the irradiation day, the dose rate at 80 cm from the source was 62.47 mSv/min. Irradiation times and appropriate distances for achieving the desired dose-equivalents were set according to this rate.

Fig. 1. Picture of a badge with Cd-Pb filter embeded in the both sides.

For irradiation of dosimeteres with thermal neutrons, the thermal beamline of Isfahan MNSR with 25 cm diameter was used for which 90% of exiting neutrons were thermal with energies lower than 0.625 eV, a stable dose rate 9.49×10^{-3} Sv/h and a flux 2.37×10^5 1/cm^{2}s. In a previous work it was shown that this beamline can be used as a calibration source of thermal neutrons [3]. After the irradiations, the radiographic films were processed in a suitable soultion in Parsian Company and the net optical densities were measured using Eq. (1). The desired optical density for any dose value was calculated as the average of the three optical densities. Then, the calibration curves in the both fields were plotted. Finally, the contributions of thermal neutrons and the gamma rays dose-equivalent were derived using Eqs. (2) and (3), respectively:

$$H_n = \frac{H_{Cd-Pb} - H_{Sn-Pb}}{F_1} \quad (2)$$

$$H_\gamma = H_{Sn-Pb} - \frac{H_n}{F_2} \quad (3)$$

where $H_{Cd\text{-}Pb}$ and $H_{Sn\text{-}Pb}$ were the dose obtained by the calibration curves beneath the Cd-Pb and Sn-Pn filters, respectively, when the film badge was irradiated in the standard ^{60}Co gamma rays field. F1=2.25 and F2=3 were the correction factors [2].

Results and discussion

The calibration curve of the film under Cd-Pb filter obtained in the ^{60}Co field is shown in Fig. 2. Similar curve is also obtained for the Sn-Pb filter. Figure 3 shows the variation of the optical density under Cd-Pb filter versus the optical density under Sn-Pb filter. As can be seen, the both filters result in similar sensitivity to gamma rays. In addition, Fig. 4 shows the calibration curves under the two filters in the mixed thermal neutron-gamma field of Isfahan MNSR. Clearly, the OD values under Cd-Pb filter are greater than Sn-Pb filter due to the excess contribution of neutron induced gamma rays. Table 1 represents the dose-equivalent values of thermal neutrons and the mixed gamma rays. It can be observed that the neutron dose values are measured with 50% uncertainty relative to the nominal values.

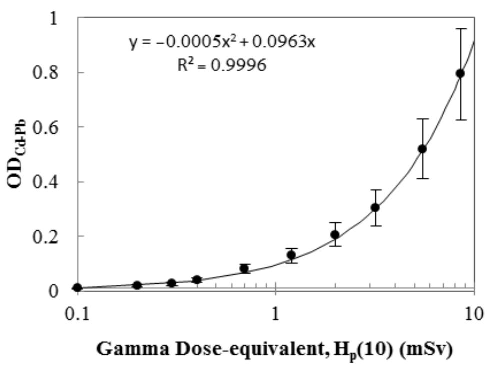

Fig. 2. Calibration curve of the film badge under Cd-Pb filter obtained in ^{60}Co gamma ray field of Karaj SSDL.

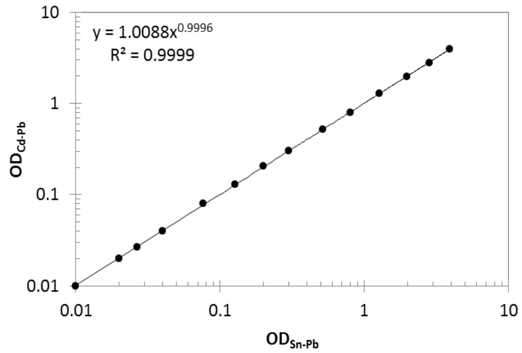

Fig. 3. Variation of the optical density under Cd-Pb filter vs. the optical density under Sn-Pb filter. The film has similar sensitivity to gamma rays under these filters.

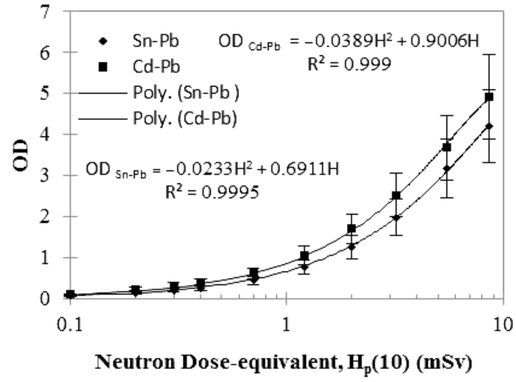

Fig. 4. Calibration curves of the film badge under Cd-Pb and Sn-Pb filters obtained in the mixed field of Isfahan MNSR.

Table 1. Dose-equivalent values of thermal neutrons and the mixed gamma rays in Isfahan MNSR.

Neutron dose* (mSv)	Measured neutron dose (mSv)	Measured gamma dose (mSv)
0.1	0.07 ± 0.01	0.64 ± 0.09
0.2	0.42 ± 0.06	1.06 ± 0.16
0.3	0.54 ± 0.08	1.53 ± 0.23
0.4	0.65 ± 0.10	2.09 ± 0.31
0.7	0.83 ± 0.12	3.86 ± 0.58
1.2	1.69 ± 0.25	6.93 ± 1.04
2.0	2.94 ± 0.44	12.57 ± 1.89
3.2	4.35 ± 0.65	22.43 ± 3.36
5.5	5.07 ± 0.76	43.50± 6.53
8.6	8.51 ± 1.28	65.10 ± 9.57

* These values are the nominal doses used for the calibration.

It should be mentioned that only slow emulsion of the film is used in this work which saturates for the gamma ray doses greater than 65 mSv as is the case in MNSR.

Conclusions

In this work, for the first time in Iran film badge dosimeter is investigated as a substitution for SSNTDs and TLDs in personal dosimetry of thermal neutrons. This dosimeter simultaneously determines the dose fractions of thermal neutrons and gamma rays by mean of Cd-Pb and Sn-Pb filters. The maximum uncertainty in the dose-equivalent of thermal neutrons is 50% lying within the range acceptable for the personal dosimetry [4].

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