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Experimental study of the film badge as an alternative personal dosimeter for thermal neutrons

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HIGHLIGHTS

- Film badge has is experimentally investigated as an alternative dosimeter for thermal neutrons.
- A Cd-Pb filter with the same sensitivity of Sn-Pb filter is used to determine neutron dose.
- With Cd-Pb filter in the badge, the dose fractions of neutrons and gamma rays can be measured.
- Between 0.1 and 10 mSv, the neutron dose-equivalent differs 50% from the nominal values.

ABSTRACT

In the present work performance of film badge as an alternative personal dosimeter for thermal neutrons is investigated. To do this, a cadmium-lead (Cd-Pb) filter with the same thickness as the tin-lead (Sn-Pb) filter is attached to the AERE/RPS badge. Since thermal neutrons are mixed with gamma rays, the dosimeter is irradiated by the Co-60 gamma rays standard field of Karaj Secondary Standard Dosimetry Lab as well as the mixed neutron-gamma field of the radiography beamline of Isfahan Miniature Neutron Source Reactor. In the both fields, ten personal dose-equivalent values between 0.1 to 10 mSv are chosen. For any dose, three film badges are used and the net optical density is determined as the average of their optical densities. Finally, the calibration curves of the film badge are plotted to determine the dose-equivalent values. Obtained results reveal that film badge simultaneously determines the thermal neutrons and gamma rays dose fractions. Also, the thermal neutron doses are at most 50% different from the nominal values considered.

KEYWORDS
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1 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 (Knoll, 2010). In situations which use of these dosimeters is not feasible, choosing an alternative one becomes important. It is shown that film badge dosimeters which are commonly used for gamma rays, can be used as an alternative for dosimetry of thermal neutrons (Jones and Marshall, 1964).

A film badge includes a radiographic film embedded in a plastic badge with different filters. The sensitive volume of the radiographic film is an emulsion layer coated on a polystyrene base. In the emulsion silver halide grains of micrometer size are suspended in gelatin. Sensitivity of the film to incident radiation depends chiefly on the size and number of the silver halide grains. For less sensitivity smaller grains with fewer number is prepared. The effect of radiation on the film appears in the form of a darkness generated by silver atoms. This darkness is called the optical density (OD) and can be quantified by using a densitometer according to Eq. (1):

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

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.

The metallic filters in the badge with appropriate materials and thicknesses enable estimating the dose of radiation with different energies. Applying a metallic filter

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Figure 1: Picture of AERE/RPS badge with Cd-Pb filter embedded in the both sides.

possessing high interaction cross-section with thermal neutrons, such as cadmium, enables the film badge to measure neutron dose. Thus, Cd-Pb filter has been used for this purpose (Jones and Marshall, 1964). 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, in order to distinguish the OD of thermal neutrons from the total value in the mixed field, the Cd-Pb must be as sensitive to gamma rays as the Sn-Pb filter. 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.

Eventually, subject of this work is to investigate the performance of film badge as a personal dosimeter for thermal neutrons.

2 Materials and methods

In this work AERE/RPS badge (Adams et al., 1965) was utilized. It is equipped with an aluminum (Dural; 1 mm) filter and a Tin-lead (Sn-Pb; 0.7 mm, 0.3 mm) filter for X and gamma rays. It has been commonly applied for personal dosimetry in the photon fields in Iran. As shown in Fig. 1, a Cd-Pb filter was placed between Sn-Pb and aluminum filters in the both sides badge as shown in Fig. 1. The radiographic films with 3 cm×4 cm dimension (FOMA company) were used. Ten dose equivalent values, Hp(10), from 0.1 mSv to 10 mSv were selected. For any dose value including the background, three film badges were used to reduce the statistical uncertainty.

First, the dosimeters were irradiated with Co-60 gamma rays of the standard field of Karaj Secondary Standard Dosimetry Lab (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^{-1}. Irradiation times and appropriate distances for achieving the desired dose-equivalents were set according to this rate.

Then, for irradiation of dosimeters with thermal neutrons, the thermal beamline of Isfahan Miniature Neutron Source Reactor (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^{-1} and a flux 2.37×10^5 cm^{-2}.s^{-1} (Dastjerdi et al., 2019). In the previous work, it was shown that this beamline can be used as a calibration source of thermal neutrons (Moslehi et al., 2022). After the irradiations, the radiographic films were processed in a suitable solution and the net optical densities (difference of the irradiated and unirradiated optical densities) were measured using Eq. (1). The desired optical density for any dose value was calculated as the average of the optical densities measured for the three films used. After finding the optical densities, the calibration curves (variation of the optical density vs. dose-equivalent) in the both gamma and neutrons fields were plotted. Finally, the contributions of thermal neutrons and gamma rays dose-equivalents were derived using Eqs. (2) and (3), respectively:

$$H_n = \frac{H_{\mathrm{Cd-Pb}} - H_{\mathrm{Sn-Pb}}}{F_1} \tag{2}$$

$$H_\gamma = H_{\mathrm{Sn-Pb}} - \frac{H_n}{F_2} \tag{3}$$

where $H_{\mathrm{Cd-Pb}}$ and $H_{\mathrm{Sn-Pb}}$ were the dose-equivalent obtained from the calibration curves beneath the Cd-Pb and Sn-Pn filters, respectively, after irradiation of the film badges by the Co-60 gamma rays field of Karaj SSDL. In the above equations, $F_1 = 2.25$ and $F_2 = 3$ were the correction factors (Jones and Marshall, 1964) added for considering the effect of cadmium gamma rays on the other parts of the film and also activation of the film under the filters rather than Cd-Pb filter.

3 Results

The calibration curve of the film under Cd-Pb filter obtained in the Co-60 field of Karaj SSDL 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 vs. the optical density under Sn-Pb filter.

Table 1: Dose-equivalent values (in mSv) of thermal neutrons and the mixed gamma rays in Isfahan MNSR. The values on the first column are the nominal doses used for the calibration.

Nominal neutron dose	Measured neutron dose	Measured gamma dose
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

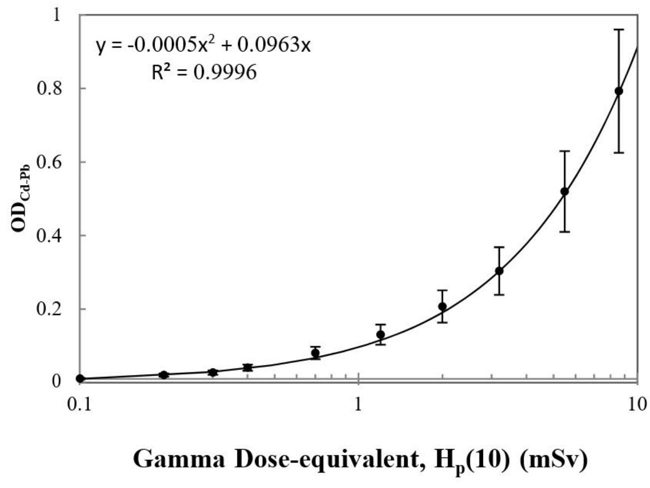

Figure 2: Calibration curve of the film badge under Cd-Pb filter irradiated by Co-60 in Karaj SSDL.

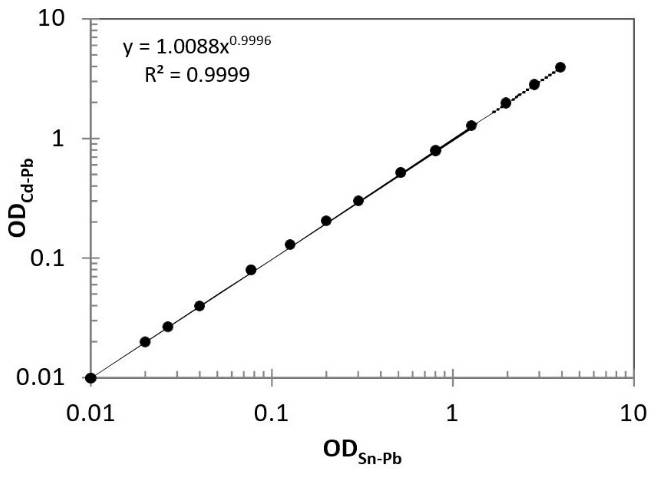

Figure 3: Variation of the film optical density under Cd-Pb filter vs. the optical density under Sn-Pb filter. The film has similar sensitivity to gamma rays under these filters.

As can be seen, the both filters have 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.

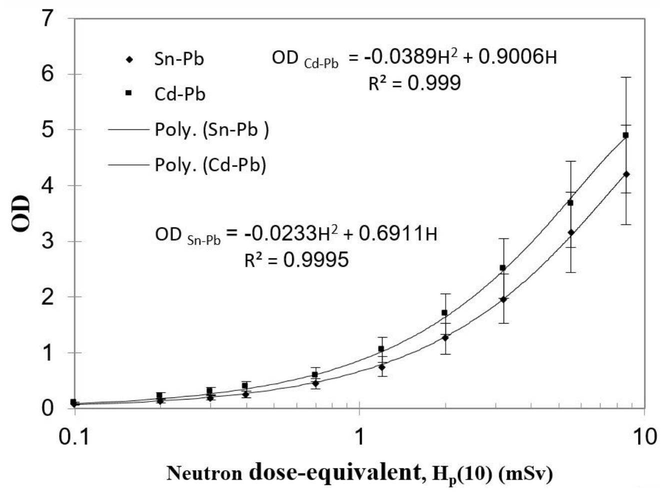

Figure 4: Calibration curves of the film badge under Cd-Pb and Sn-Pb filters irradiated by the mixed field in Isfahan MNSR.

4 Discussion

Obtained data revealed that the neutron dose values measured by the film badge are at most 50% different from the nominal values in the MNSR field. It should be mentioned that only slow (high sensitive) 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.

Another point is that in Isfahan MNSR, the dosimeters cannot be irradiated with phantom. Because the reactor and its thermal beamline are located inside a water pool located in the floor of the reactor hall. Hence, effect of this issue on the dose measured by the film badge needs to be evaluated. It is shown that (Jones and Marshall, 1964; Moslehi et al., 2022) by considering the average number of thermal neutron reflections between air and water (the case with phantom) and in the air (the case without phantom), the maximum difference between the dose-equivalent measured in the both above cases will be 15%.

5 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. Using the Cd-Pb and Sn-Pb filters with similar sensitivity to gamma rays, this dosimeter determines the dose fraction of thermal neutrons using the Cd filter. It also enables to extract the dose fraction of gamma rays mixed with thermal neutrons. The maximum discrepancy between the measured and the nominal dose-equivalent values of thermal neutrons is 50% lying within the range acceptable (−30% to +50%) for the personal dosimetry reported in the IAEA safety standard GSG-7 (IAEA, 2018).

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