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Comparison and Correction of Thermo-Luminescent Responses in Different Neutron Fields

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ABSTRACT

Introduction: Neutron dosimetry is a challenging subject in radiation protection. Responses of neutron dosimeters mostly depend on the neutron energy spectrum. Dosimeter response corresponding to a dose-equivalent in the calibration field is different from responses in other neutron fields. Consequently, the dose estimated by neutron dosimeters may be associated with great uncertainty. Therefore, the present study aimed to modify the response in different neutron fields in order to reduce this uncertainty.

Material and Methods: Thermo-luminescent dosimeters (TLDs) are widely used to determine neutron dose-equivalent. In the present study, a set of TLD-600 and TLD-700 dosimeters included in a TLD card was utilized to determine the response to "fast" neutrons of ^{241}Am-Be,^{252}Cf, and ^{239}Pu-Be standard fields in four dose-equivalents of 5, 10, 15, and 20 mSv. Meanwhile, ^{241}Am-Be was regarded as the calibration field.

Results: As evidenced by the obtained results, for equal dose-equivalents, the original responses in ^{252}Cf and ^{239}Pu-Be fields are smaller, compared to those in the ^{241}Am-Be filed. The maximum discrepancies were obtained at 26.8% and 42.5% occurring at 20 and 5 mSv, respectively. After the application of a correction factor equal to the average of relative responses (i.e., in ^{241}Am-Be to two other fields) corresponding to all dose-equivalents considered, these differences reduced to 12.4% and 21.7%.

Conclusion: It can be concluded that the correction method used in the present study could enhance the accuracy of dose estimated by TLDs in fast neutron fields.

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Introduction

The major source of radiation exposure is related to natural radionuclides. Natural radionuclides can be divided into two categories, namely terrestrial radionuclides and cosmic rays. According to the International Atomic Energy Agency (IAEA) report, 80% of the radiation to which a person is exposed during one year is from natural radionuclides [1] through inhaling radon gas, external and internal exposure to terrestrial radionuclides, and external exposure to cosmic rays. The natural radioactivity levels are different worldwide due to geographical and geological conditions [2]. The natural radioactivity in soil comes mainly from uranium and thorium series and a radioactive isotope of potassium. It is of utmost importance to have knowledge about the levels of background radiation for impact assessment in the future, radiation protection, and exploration [3-8]. Concentrations of terrestrial radionuclides about certain permissible levels in the soil may become a health hazard leading to increased risk of cancer in the high background level areas [9,10]. The mortality rates of gastrointestinal cancers have been reported high in Mazandaran province, and this province is considered a high-risk area [11]. It was also reported that mortality rates were related to different parameters, such as the impact of the geographical region [12]. This study aimed to describe the methodology to find out the possible relationship between the reported mortality rates and levels of natural radionuclides in the soil of the areas under study. For this reason, the activity concentration of natural radionuclides was determined in 61 surface soil samples collected from Mazandaran province, Iran. The radiological indices were estimated using the measured concentrations, and finally, the association between the potential radiological hazards and the collected samples were investigated in this study.

Materials and Methods

The dosimeters employed for dose measurements in the current study included Harshaw ^{6}LiF: Mg, Ti and ^{7}LiF:Mg,Ti thermoluminescent (Harshaw Co., USA) pair crystals (TLD-600 and TLD-700). A TLD card, consisting of four crystals (chip), was used as depicted in Figure 1. It includes two TLD-600 and two TLD-700

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crystals. The TLD-700 is composed of 95.12% 7Li and 4.38% 6Li, while TLD-600 consists of 0.03% 7Li and 99.47% 6Li. The amount of Ti and Mg impurities in the TLDs are in the order of ppm. Since TLD-600 is sensitive to both gamma-ray and neutrons, TLD-700 (only sensitive to gamma rays) was used to separate the contribution of gamma ray from neutrons. The TLD crystals have a dimension of 3.1 mm×3.1 mm×0.4 mm. The TLD card was placed on ISO slab phantom with a dimension of 30 cm×30 cm×15 cm made of Polymethyl Methacrylate (PMMA) walls and filled with water. The 241Am-Be, 252Cf, and ^{239}Pu-Be as the standard sources of calibration laboratories in the Atomic Energy Organization of Iran (AEOI) were used as neutron fields in the present study. Their characteristics are presented in Table 1. The TLD card was located at a distance of 1 m from the sources, and all experimental setups were placed in the air. The schematic view of the irradiation setup is displayed in Figure 2.

Table 1. Characteristics of standard calibration neutron sources used in the study

Standard source	Activity (Ci)	Emission rate (n/s)	Dose-equivalent rate at 1 m (µSv/h)
^{241}Am-Be	9.65	1.97 ×10^{7}	228
^{252}Cf	2.2	2.28 ×10^{7}	6780
^{239}Pu-Be	2.5	1.66 ×10^{7}	198

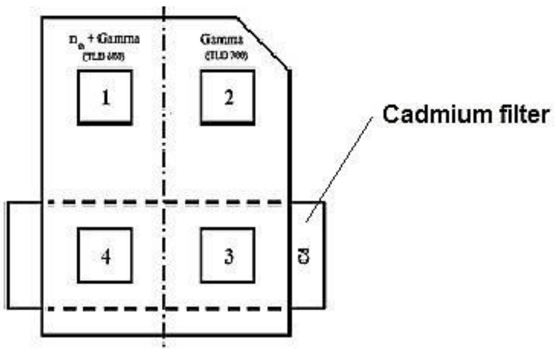

Figure 1. Schematic view of the TLD card used in the study, TL_1 and TL_4 are TLD-600, while TL_2 and TL_3 are TLD-700.

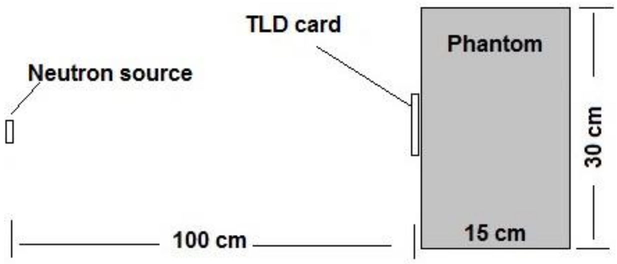

Figure 2. Schematic view of the setup for irradiation of thermo-luminescent dosimeter card in a neutron field

With knowledge of dose-equivalent rates of the three standard sources in separate irradiations, time is set in such a way that dose-equivalents of 5, 10, 15, and 20 mSv are received by the TLD card in any field. The calibration of all TLDs is carried out in the 241Am-Be field. The TLD reader Harshaw model 6600 is also used for reading the TLDs. The contributions of TL dosimeter in the card are defined as follows and displayed in Figure 1:

TL_1 (TLD-600): Thermal neutrons (n_{th})+albedo neutrons + gamma rays
TL_2 (TLD-700): gamma rays
TL_3 (TLD-700): gamma rays
TL_4 (TLD-600): Thermal neutrons (n_{th})+gamma rays

The TL_1 is the total dose obtained by the summation of gamma-ray dose, thermal neutron dose, and albedo neutron dose (backscattered from phantom). The TL_2 is the gamma-ray dose. The TL_3 is similar to TL_2; nonetheless, the effect of thermal neutron dose is eliminated by the Cd filter. The TL_4 is only the summation of gamma-ray dose and thermal neutron dose (the effect of thermal neutron dose is eliminated by Cd filter).

The response of a given TLD in the card is obtained using Equation 1 [1]:

$$TL'_i = TL_i \times \frac{RL_0}{RL_i} \times ECC_i - TL_{ib} \times \frac{RL_0}{RL_{ib}} \times ECC_{ib} \quad (1)$$

where TL_i (i denotes the number of TLDs) is the response of each TLD, RL_0 signifies the intrinsic response of TLD reader (using a ^{14}C radioactive source as the reference light), RL_i is the intrinsic response corresponding to any TLD, and ECC_i is the Element Correction

The coefficient for the TLDs. Index b refers to the background. Finally, the response to "fast" neutrons can be determined by Equation 2 [12]:

$$R = (TL'_1 - TL'_4) - 0.34TL'_4 \quad (2)$$

where $0.34TL'_4$ refers to the correction of the thermal albedo factor from the cadmium filter in the TLD card [12]. The contribution of gamma rays in response is subtracted from the neutrons. It is noteworthy that for each dose-equivalent in every neutron field, four measurements are carried out and the related response is the average of four responses.

Results

Variation of TLD response in terms of nano coulomb (nC) versus dose-equivalents in the three neutron fields is illustrated in Figure 3. Error bars show one standard deviation of the data. Moreover, Table 2 presents the data points plotted in this figure. The difference (in %) of responses in ^{252}Cf and ^{239}Pu-Be fields from ^{241}Am-Be are also provided.

The standard deviations are related to the sources of uncertainties associated with TL dosimeters regarding GSR part 3 and GSG-7 standard documents [13, 14]. The GSR part 3 introduces the radiation protection and the safety procedures required for radiation sources, while GSG-7 describes the standards and conditions for occupational radiation protection. The uncertainty sources are induced by dosimetry systems that briefly include inhomogeneity of detector sensitivity, reader stability, reference calibration, energy and angle of exposure, and fading of TLD chips. They are about 20% with a 95% confidence level. As illustrated in Figure 3, the TLD response increases with increasing the dose-equivalent according to the linearity characteristics of TLDs in all three neutron fields. Moreover, for any dose-equivalent, the response to ^{241}Am-Be neutrons is larger, as compared to the response in ^{252}Cf and ^{239}Pu-Be fields. The maximum discrepancies are 26.8% and 42.5% occurring at 20 and 5 mSv, in ^{252}Cf and ^{239}Pu-Be fields, respectively.

The difference of responses in the calibration field from the other fields can be described by different neutron energy spectra. Neutron interactions and the related cross-sections strongly depend on its energy. The contribution of interactions leading to an observable response caused by that energy will vary when the probability of a given energy is not similar in different spectra. Since fast neutron response was merely considered in the present study, and the ^{241}Am-Be spectrum has more fast neutrons, compared to the other fields considered here, it is evident that its response is more than the other neutron sources.

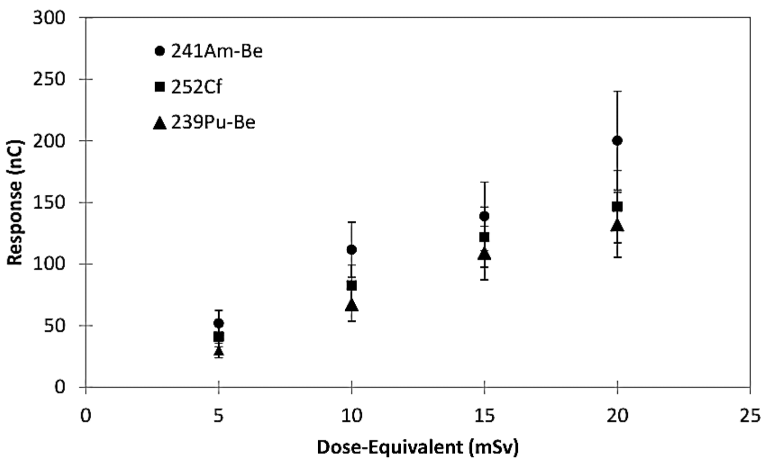

Figure 3. Thermo-luminescent dosimeter response vs. dose-equivalents in three different neutron fields, Error bars show one standard deviation of the data.

Table 2. Original response of thermo-luminescent dosimeters (nC) to fast neutrons of ^{241}Am-Be, ^{252}Cf, and ^{239}Pu-Be fields. Difference (%) of responses in ^{252}Cf and ^{239}Pu-Be fields from those in ^{241}Am-Be

Dose-Eq. (mSv)	^{241}Am-Be	^{252}Cf	Diff. (%)	^{239}Pu-Be	Diff. (%)
5	51.98±10.40	41.12±8.22	20.89	29.90±5.98	42.50
10	111.64±22.33	82.61±16.55	26.00	67.15±13.43	39.85
15	138.80±27.76	121.86±24.37	12.20	108.95±21.79	21.50
20	200.16±40.03	146.59±29.32	26.76	131.86±26.37	34.12

Discussion

As displayed in Table 2, due to the dependency of TLD response on neutron energy, the responses corresponding to equal dose-equivalents are not the same. This may reduce the accuracy of dose estimation in neutron fields for occupational exposure control. Therefore, to improve the accuracy required for neutron dosimetry, it is important to reduce the variation of responses in different fields.

To achieve this goal, the responses in ^{241}Am-Be fields relative to the corresponding responses in the two other fields were initially calculated. Table 3 presents the relative responses using the data in Table 2 and the average of these relative responses. Subsequently, this average is multiplied by the responses provided in Table 2. Finally, the corrected responses and their differences from the calibration field (i.e., ^{241}Am-Be) are listed in Table 4.

Furthermore, they are illustrated versus dose-equivalent in Figure 4. It is obvious that after this correction, the differences observed between the responses in the three neutron fields are reduced. The maximum discrepancies between 252Cf and 239Pu-Be fields are 12.34% and 21.66%, respectively, as compared to 241Am-Be. Based on a comparison between Tables 2 and 4, for 5, 10, and 20 mSv, the differences are reduced dramatically. Although the responses for 15 mSv changed after correction, their differences from the original data remained almost intact.

Table 3. Responses of thermo-luminescent dosimeters in $^{\text{the } 241}$Am-Be field relative to the other fields

Dose-Eq. (mSv)	^{241}Am-Be/^{241}Am-Be	^{241}Am-Be /^{252}Cf	^{241}Am-Be /^{239}Pu-Be
5	1.00	1.27	1.74
10	1.00	1.35	1.67
15	1.00	1.17	1.27
20	1.00	1.37	1.52
Correction factor	Average = 1.00	1.28	1.55

Table 4. Corrected responses of thermo-luminescent dosimeter (nC) to fast neutrons of ^{252}Cf and ^{239}Pu-Be fields and their difference from ^{241}Am-Be

Dose-Eq. (mSv)	^{241}Am-Be	^{252}Cf	Diff. (%)	^{239}Pu-Be	Diff. (%)
5	51.98±10.40	52.63±10.52	1.25	46.35±9.27	10.83
10	111.64±22.33	105.74±21.84	5.28	104.08±20.82	6.77
15	138.80±27.76	155.98±31.19	12.37	168.87±33.77	21.66
20	200.16±40.03	187.64±37.52	6.25	204.38±40.87	2.11

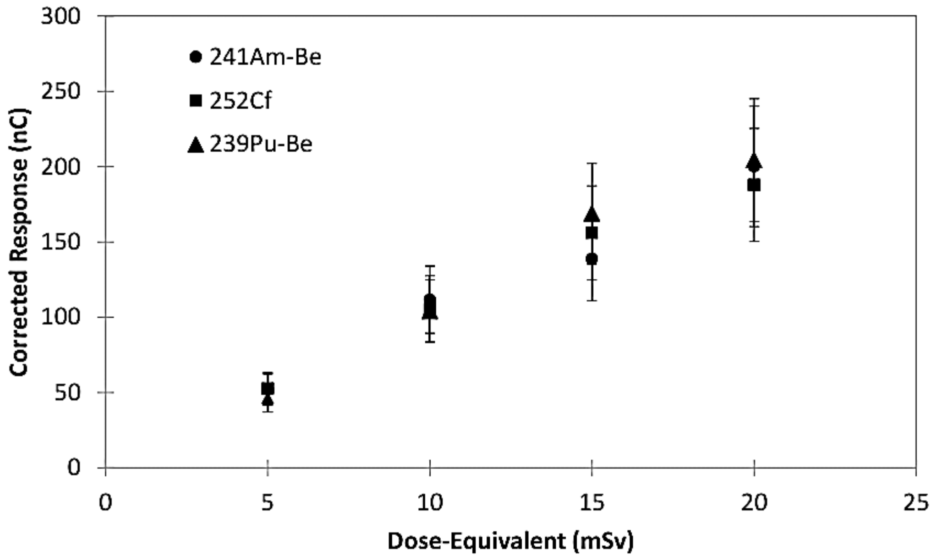

Figure 4. Corrected thermo-luminescent dosimeter response vs. dose-equivalent in three different neutron fields

Conclusion

The response of a set of TLD-600/700 dosimeters for a few dose-equivalents of fast neutrons in 241Am-Be, 252Cf, and ^{239}Pu-Be standard sources were measured. Moreover, 241Am-Be was used as the calibration field. As evidenced by the obtained results, at a given dose-equivalent, the responses to 252Cf and ^{239}Pu-Be neutrons are smaller, compare to the response to 241Am-Be neutron. It refers to the strong sensitivity of the responses to the neutron energy. Therefore, a new correction factor equal to the average of relative responses (in the calibration field to the other fields) will compensate for the responses. In light of the findings of the study, it can be concluded that the accuracy of dose estimation can be enhanced using the TLDs in different neutron fields.

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