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Performance of Sife - Eldeen dosimeter over broad absorbed dose and dose rate ranges of γ – radiation and at different temperatures

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Background: Results are presented on some dosimetric characteristics of Sife – Eldeen dosimeter based on the radiation induced conductivity (RIC) of 3.5 M aqueous urea solutions. The studied characteristics were the response (RIC) of Sife – Eldeen dosimeter in broad ranges of absorbed dose, dose rates and at different irradiation temperature. *Materials and Methods:* Kent EIL5007 conductivity meter (Kent industrial measurements–Brown Boveri) was used for the measurement of samples RIC. *Results:* RIC of 3.5M urea aqueous was studied at low (0 – 462 Gy), as well as, at high (0 - 2592 kGy) absorbed radiation dose ranges. The coefficient of variation CV%, associated with RIC measurement of 3.5 M urea solution as a function of absorbed radiation dose, was found to be not more than 3.5% for both high and low absorbed radiation dose ranges. The effect of dose rate on RIC was studied in the range 0.035 - 5.969 kGy/h. The temperature effect on this system, at different doses, was also studied. *Conclusion:* The obtained results show the importance of using this dosimeter for dose evaluation in industrial gamma radiation processes , as well as in medical fields. **Iran. J. Radiat. Res., 2008; 6 (3): 135-140**

Keywords: *Sife – Eldeen dosimeter, liquid chemical dosimeters, γ – Radiation, Urea, Electrical conductivity.*

INTRODUCTION

The energy of ionizing radiation produces a chemical change in the absorbing medium, and the amount of this chemical change may be used as a measure of absorbed dose. Basic requirements of a dosimeteric system are to be sensitive to radiation in a wide dose range, stable radiation induced response over a long time period, tissue equivalence, as well as, easy, fast readout of absorbed dose and law cost of ingredients. Radiation dosimetric studies on hydrated urea were carried out by few workers [1, 2]. Hintenlang *et al.* [1] evaluated the radiation effects on hydrated urea for both photon and neutron irradiations via nuclear quadruple resonance techniques (NQR). They found that hydration of urea provides a greatly increased sensitivity to both forms of radiation exposure. Accordingly, they considered hydrated urea as a prime candidate for radiation dosimetry for several areas of radiation processing such as food irradiation dosimetry. The author [2] studied γ-radiation induced electrical conductivity (RIC) of 3.5 M aqueous urea solution (Sife - Eldeen dosimeter). This study indicated that, the absorbed radiation dose could be determined via RIC measurements. Knowing that, RIC measurement is one of the several methods applied to determine absorbed dose [3-10]. The aim of the present work is to characterize the response of Sife - Eldeen dosimeter (SED) in broad ranges of absorbed dose, dose rates and at different irradiation temperature.

MATERIALS AND METHODS

Preparation of SED and irradiation

Urea 99% pure from Adwic was dissolved in double-distilled water for the preparation of SED (3.5 M aqueous urea solution) [2]. Urea solution samples were irradiated isotropically at electronic equilibrium conditions with γ-radiation using ^{60}Co source (India Gamma chamber 4000 A, India and GC40 Nordon,Canada Cs-137) in 50 ml bottles with tight glass stopper. All of the reported experimental work was done on aqueous naturally aerated solutions at

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ambient temperature. Temperature controlled experiments were performed in thermostatic condition at 0, 20, 35, 45, 60 °C after being conditioned to a given equilibrium temperature prior to irradiation.

Fricke solution was used as reference dosimeter to determine absorbed dose rates of the radiation facilities. The absorbed radiation dose correction was applied for the difference in electron densities of 3.5 M aqueous urea solution and fricke dosimeter solutions.

Electrical conductivity measurements

RIC of the irradiated solutions was measured, immediately after irradiation at ambient temperature, using Kent EIL5007 conductivity meter (Kent industrial measurements–Brown Boveri).

RESULTS

Results are presented on some dosimetric characteristics of SED based on, a novel phenomenon, i.e., RIC of 3.5 M aqueous urea solutions. 3.5 M urea concentration is the proper concentration for obtaining the best sensitivity of the dosimeter [2].

Effect of absorbed dose on RIC

The RIC, of 3.5 M urea aqueous solution (SED), was studied as a function of absorbed dose at both low (0 - 462 Gy) and high dose ranges (0 - 2592 kGy).

Low dose range

Characterization of a dosimeter performance in low absorbed dose range is demanded, for both medical and biological studies. The response of SED was studied in a low dose range between 0 and 462 Gy using ^{137}Cs irradiator (0.035 kGy/h). A linear dependence (R^2= 0.9898), of the dosimeter response (RIC) on the absorbed radiation dose up to 462 Gy, is shown from figure1.

High dose range

The response was measured in the absorbed-dose range 0 – 2592 kGy (figure 2). An overall equation was determined for the dose – response dependence of SED in this range;

$$y = -0.001x^2 + 5.4636x + 80$$

It was found that the RIC depends, linearly (R^2=0.9938), on absorbed radiation dose in the range 0 - 595 kGy (figure 3) and tends to saturate at higher absorbed radiation dose, as indicated by the departure from linearity above this dose (figure 2).

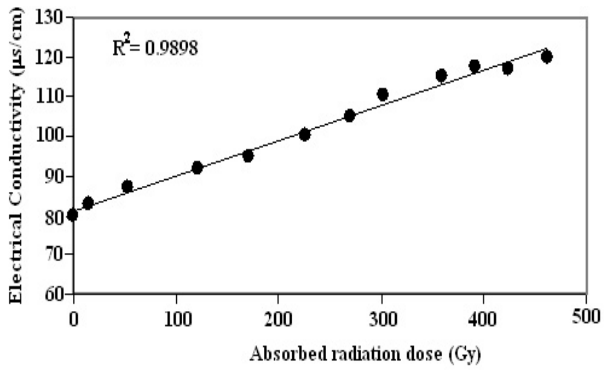

Figure 1. Dose response of SED at low dose range 0-462Gy using ^{137}Cs gamma radiation at 0.035kGy/h.

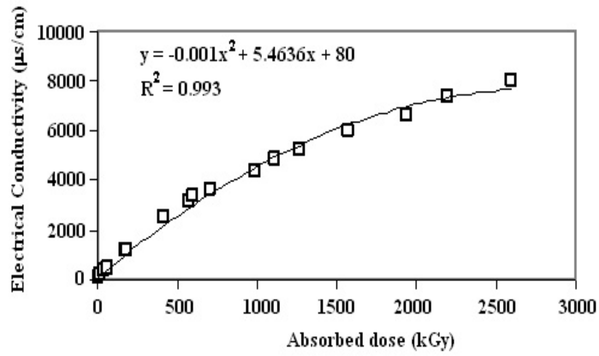

Figure 2. Dose response of SED at high dose range 0 - 2592 kGy using ^{60}Co gamma radiation at 5.969 kGy/h.

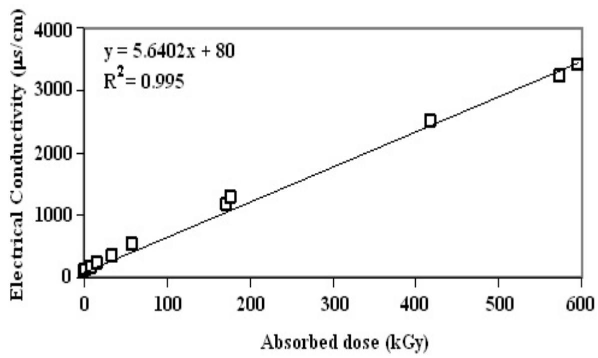

Figure 3. Dose response of SED in the range 0-595 kGy using ^{60}Co gamma radiation at 5.969 kGy/h.

Uncertainty (type A) associated calibration curves

For 3.5 M aqueous urea solution system the coefficient of variation CV % associated with RIC measurement (three readings for of each data point) as a function of absorbed radiation dose was calculated for both studied dose ranges. In the low dose range (0 - 462 Gy), CV % found to be 2.7 and the uncertainty (type A) was found to be 5.4 % and 8.1 % for 95 % and 99 % confidence levels, respectively. In the high dose range (0 - 2592 kGy), CV % associated with RIC measurement as a function of absorbed radiation dose was found to be 3.5 and the uncertainty (type A) was found to be 7.0 % and 10.5% for 95 % and 99 % confidence levels, respectively. The method used to calculate the uncertainties is consistent with international standards (ISO, 1993; ISO/ASTM, 1995).

Effect of dose rate on RIC

Urea solutions, 3.5 M, were irradiated with 0.25, 0.50, 5, 10, 30 kGy of gamma radiation, at 0.035, 0.828, 2.933, 5.969 kGy/h, for studying dose rate - RIC dependence of SED. It is apparent from this study that, RIC is independent on dose rate at 5 and 10 kGy absorbed dose within the dose rate range 0.828 - 5.969 kGy/h (figure 4). In the same dose rate range, at 30 kGy absorbed dose, a slight decrease in RIC is observed as dose rate increases with a coefficient of -4.858 $\mu S.cm^{-1}/ kGy.h^{-1}$ (figure 4). The RIC dependence on dose rate, at low absorbed doses (0.25, 0.50 kGy), is shown in Fig.5. It is apparent from this study that, RIC decreases as dose rate increase in the range 0.035 - 0.828 kGy/h with coefficients, -22.642 $\mu S.cm^{-1}/kGy.h^{-1}$ for 0.25 kGy absorbed doses and -86.792 $\mu S.cm^{-1}/ kGy.h^{-1}$ at 0.5 kGy absorbed doses. While RIC seems to be constant as dose rate increases up to 5.969 kGy/h.

The dependence of the dosimeter sensitivity ($\mu S.cm^{-1}$ / kGy) on dose rate (kGy/h) was also studied. Table 1 shows that the sensitivity is a maximum at 0.035 kGy/h and decreases as dose rate reaches 0.828 kGy/h. The sensitivity is at similar values in the dose rate range 0.828 - 5.969 kGy/h.

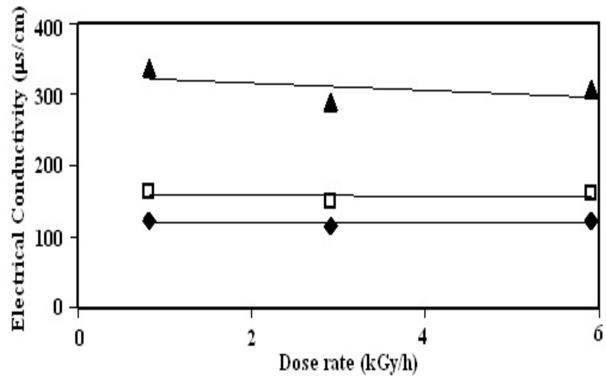

Figure 4. Effect of dose rate (kGy/h) on RIC (µs/cm) at 5 (♦),10 (□),30 (▲) kGy absorbed doses.

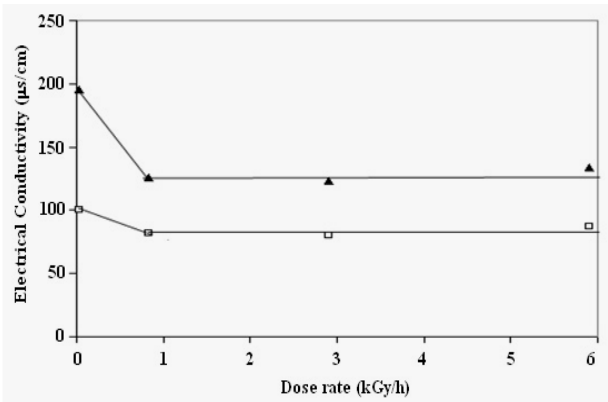

Figure 5. Effect of dose rate (kGy/h) on the RIC (µs/cm) at 0.25□ and 0.50 kGy ▲ (× 1.5).

Table 1. Dependence of SED sensitivity ($\mu S.cm^{-1}$ / kGy) on absorbed dose rate (kGy/h).

Dose rate (kGy/h)	Sensitivity ($\mu S.cm^{-1}$ / kGy)
0.035	93.239
0.828	8.542
2.933	6.973
5.969	7.513

Effect of irradiation temperature on RIC

Experiments are being planned on the response of the dosimeter at normal temperatures of commercial gamma irradiators, at sterilization doses, as well as higher and lower temperatures. Therefore, the dosimeter solutions were irradiated to set of dose levels of 0.5, 1.0, 5, 10, 50 kGy at 0, 20, 35, 45, 60°C. The effect of irradiation temperature (0 – 60 °C) on the dosimeter response (RIC) is shown in figure 6, whereas, the slope (sensitivity) of the linear calibrations *increases* as irradiation temperature increases.

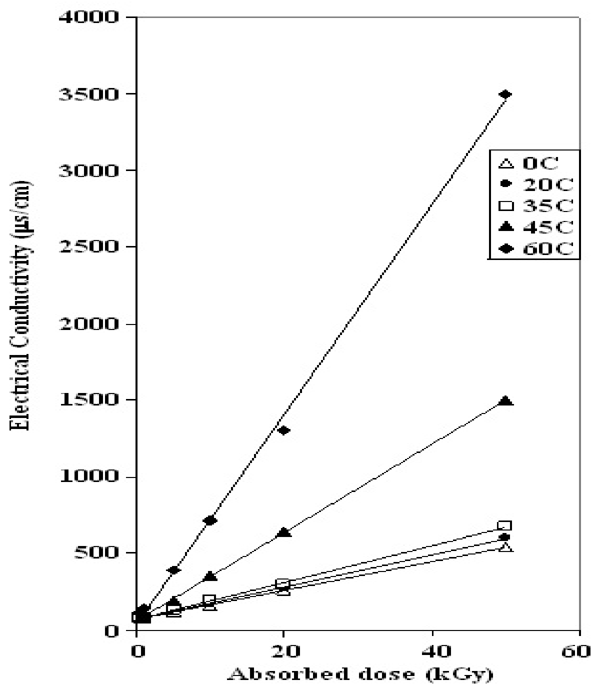

Figure 6. Effect of irradiation temperature on the RIC – absorbed dose dependence of SED (absorbed dose rate = 2.41kGy/h)

The effect of irradiation temperature on the sensitivity (µs.cm^{-1}/kGy) of SED is shown in figure 7 Where, a slight increase in the SED sensitivity was observed in the 0 -35°C range with an irradiation temperature coefficient of 0.075 µS.cm^{-1}.kGy^{-1}/°C. Relatively significant increase in SED sensitivity was observed as irradiation temperature increases in the 35 - 60 °C range, with a temperature coefficient of 2.0759 µS.cm^{-1}.kGy $^{-1}$/°C.

DISCUSSION

Accurate dosimetry requires a characterization of the parameters that influence the dosemeter response, such as dose, dose rate and temperature effects. It was found that 3.5 M urea concentration is the most

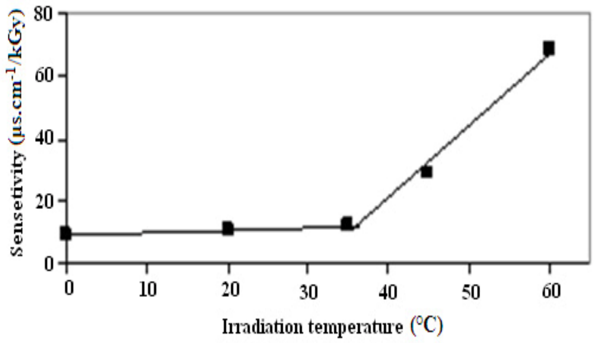

Figure 7. Effect of irradiation temperature on the sensitivity (µs.cm^{-1}/kGy) of SED (absorbed dose rate = 2.41kGy/h).

suitable to obtain a satisfactory sensitivity as well as post irradiation stability of response over several weeks at 0°C storage temperature [(2)]. Therefore, the last feature enables this system to be a documental device.

Generally, Low absorbed dose range is of interest in medical, as well as, biological fields [(11-13)]. In particularly, the range 10 - 30 Gy, is of grate interest for γ-irradiation of human blood for use in transfusion therapy [(14)]. Accordingly, characterization of the performance of SED in low dose range indicates a good linearity with a satisfactory CV%. It should be noted that the SED dosimeter is a tissue equivalent material [(2)].

This results indicate that, SED can be used in different purposes such as frozen poultry irradiation (3–4kGy), food irradiation, medical sterilization (5 – 40 kGy), and industrial radiation processes such as polymer cross-linking (40 – 250 kGy).

Moreover, comparison of dose – response range of SED with that of Fricke dosimeter, iodide/iodate dosimeter and ethanol-monochlorobenzene, indicates a satisfactory performance for the first. Whereas, the dose – response range of Fricke dosimeter, range from 10 Gy to a 500 Gy [(15)]. The upper limit of linear response for the Fricke dosimeter can be extended to 10^4 Gy by saturating the solution with oxygen and increasing the ferrous ion concentration (super-Fricke dosimeter). Also in the case of iodide/iodate dosimeter the upper limit is 6 kGy [(16)]. Moreover, absorbed dose – electrical conductivity dependence, of ethanol-monochlorobenzene dosimeter, is considered in the dose range 50 Gy – 1 MGy [6]. As better and precise data correspond to a lower value for the CV%, Sife – Eldeen dosimeter could be considered precise due to the lower CV% values for the RIC measurements at different absorbed radiation doses.

It is apparent from the study of the dose rate effect on RIC, that RIC is independent on dose rate at 5 and 10 kGy absorbed dose within the dose rate range 0.828 - 5.969 kGy/h (figure 4) which represents an advantageous feature. The SED sensitivity (μs.cm^{-1}/kGy) is at similar values in the dose rate range 0.828 - 5.969 kGy/h. Therefore, it could be stated that in this range the sensitivity is independent on the dose rate.

The effect of irradiation temperature on dosimeter response (RIC) was studied in a range (0 – 60 °C), which covers most of thermal irradiation conditions of both industrial and research irradiators. It is apparent that the slope (sensitivity) of the linear calibrations increases as irradiation temperature increases (figure 6). The dependence of SED sensitivity (μs.cm^{-1}/kGy) on irradiation temperature in the range; 0-35 °C is insignificant (0.0753 μS.cm^{-1}.kGy^{-1}/°C), which represents an advantageous feature. While, the significant sensitivity increases at higher irradiation temperatures i.e. in the range 35-60 °C, implies taking temperature coefficient in consideration (2.0759 μS.cm^{-1}.kGy^{-1}/°C).

CONCLUSION

In the low dose range (0 - 462 Gy), SED, shows an excellent linear dependence (R^2 = 0.9898) of RIC on the absorbed radiation dose. In the high dose range (0 - 2592 kGy), it was found that the RIC depends, linearly (R^2=0.9938), on absorbed radiation dose in the range 0 - 595 kGy and tends to saturate at higher absorbed radiation dose.

It is apparent from this study that, RIC is independent on dose rate at 5 and 10 kGy absorbed dose within the dose rate range 0.828 -5.969 kGy/h. In the same dose rate range, at 30 kGy absorbed dose, a slight decrease in RIC is observed as dose rate increases with a coefficient of - 4.858 μS.cm^{-1}/ kGy.h^{-1} . At low doses (0.25, 0.50 kGy), the RIC decreases as dose rate increase in the range 0.035 - 0.828 kGy/h with coefficients, -22.642 μS.cm^{-1}/ kGy.h^{-1} for 0.25 kGy and -86.792 μS.cm^{-1}/ kGy.h^{-1} at 0.5 kGy. While RIC seems to be constant as dose rate increases up to 5.969 kGy/h.

The sensitivity (μS.cm^{-1}/kGy) of the dosimeter increases as irradiation temperature increases. Where, a slight increase in the sensitivity was observed in the 0 – 35 °C range with an irradiation temperature coefficient of 0.0753 μS.cm^{-1}.kGy^{-1}/°C. Significant increase in sensitivity was observed as irradiation temperature increases in the range 35 – 60 °C with a temperature coefficient of 2.0759 μS.cm^{-1} .kGy^{-1}/°C.

Because SED is a solution, it can be used to integrate the dose over the volume of the sample. Whereas, the volume can be made of any size or shape such as blood bag.

SED complies with many requirements of personal, environmental and medical dosimetry. Whereas, this dosimeter is characterized by, tissue equivalency, high sensitivity, wide dose response range, stability of RIC, ease of handling, as well as low cost. Therefore, it could be concluded that SED is a promising dosimetric system for the verification of dose rate in food irradiation, medical sterilization and industrial radiation processes such as polymer cross-linking.

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