DETERMINATION OF THE UNCERTAINTY OF SULFONATED GRAFTED LOW DENSITY POLYETHYLENE DOSIMETER FOR ASSURING THE QUALITY OF GAMMA MEASUREMENTS AT THERAPEUTIC RADIATION LEVEL

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Abstract. In this work, one type of thermoluminescence dosimeter radiation-induced graft copolymerization of binary monomer system acrylic acid/acrylamide (AAc/AAm) (50/50) onto low density polyethylene (LDPE) films was irradiated by ^{60}Co therapeutic gamma ray dose. This work deals with the case of sulfonated grafted film which has good properties such as thermal stability, and good dosimetric properties. The various sources of uncertainty for this type of thermoluminescence dosimeter under study were analyzed. The uncertainty budget tables for radiation measurements were declared. For the used procedure, these uncertainties multiply the coverage factor equal 2 to obtain the expanded uncertainty at 95% confidence level. The combined uncertainty does not exceed 6.3%.The expanded uncertainty at 95% confidence level should be added to the value of measurements to obtain the accurate dose.

Key words: sulfonated grafted polymers, thermoluminescence, dosimetry, uncertainty.

INTRODUCTION

The thermoluminescent (TL) properties of films have been previously reported [5, 10, 11] and the grafted polymer is considered as a candidate material for radiation dosimetry in off-line measurements. TL films seem to be insensible to radiation damage [5] and exhibit high sensitivity, allowing the use of samples tailored in very small sizes when a high spatial resolution is required. This is the case in radiotherapy, when small irradiation fields are employed or when high spatial gradients of doses are present. Moreover, grafted polymers can be used for *in vivo* and in phantom measurements.

In a recent work [1] some preliminary results have been reported on the dosimetric characteristics of different diamond samples. After irradiation with a

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gamma beam from a cobalt machine, they showed a good TL sensitivity, of the same order of TLD100 dosimeters, the dose response for both were linear until 3 Gy, but the reproducibility was not satisfactory because of the presence of low temperature peaks in the glow curves, which resulted in a high thermal fading. This led us to look for new samples with different kinds of defects. A set of high-quality, recently produced, grafted polymers samples; cut from the same disk they were studied in order to determine their TL response. The dosimetric characterization includes the reproducibility, the TL response as a function of the dose and the dependence of the TL response on the radiation energy [10]. According to the literature [5, 9], TL can be used for dosimetry in individual monitoring of photons and electrons from external sources. One can derive a list of commonly encountered sources of errors that can affect the precision and accuracy in determining the dose under certain geometrical conditions [1]. The purpose of this study is to provide a better understanding of the response of sulfonated grafted polymers to gamma radiation to determine the sources of uncertainty to obtain accurate gamma dose measurement.

MATERIALS AND METHODS

In our measurements we have used 35 mm thick polymer films of sulphonated low density polyethylene grafted by acrylic acid acrylamide, acrylic acid actinamide (LDPE-g-p (AAm/AAc)).

A standard ^{60}Co-source dose was used at rate 5.672 rad/min at Radiation Dept., National Research Center, Atomic Energy Authority, Egypt.

- The farmer dosimeter of the type 2570 manufactured by Nuclear Enterprises Ltd, UK with its special ionization chamber 2571 sufficiently sensitive to γ-rays under the optimum condition of pressure and temperature was used to determine the dose rate of the ^{60}Co source.
- We used a Harshaw-Bicron 4500 TLD reader (Saint-Gobain, Paris, France) at a heating rate of 5 °C/s. The maximum reading temperature was 600 °C.
- A set of six ($5\times5\times0.3$ mm^3) high-quality grafted polymer detectors cut from different wafers have been prepared. They are transparent and polished on both sides.
- The readings must be taken after 30 min to reach the stability.

The symbols used are taken mainly from the Technical Report Series No. 374 [**7**]. The meanings have been given in the text, including the appendices, where they occur, but are repeated here for convenience of reference.

The case of interest is where the quantity y being measured, called the measurand, is not measured directly, but is determined from n other quantities x_1, x_2, … x_n through a functional relation f, often called the measurement equation: $y = f(x_1, x_2, \ldots x_n)$.

Us (standard uncertainty) = positive square root of the sum of the square quantities Us^2. Each component of uncertainty, however evaluated, is represented by an estimated standard deviation, termed standard uncertainty with suggested symbol *Us*, and equal to the positive square root of the estimated variance.

Ci – sensitivity coefficient used to multiply an input quantity x_i to express it in terms of the output quantity *y*.

U (expanded uncertainty) = $Us \times K$ (coverage factor, $K = 2$, in confidence level 95%).

Uc(y) (combined uncertainty) = the positive square root of the combined variance:

$$U^2c(y) = \sum (\partial f/\partial x_1)^2\ U^2(x). \tag{1}$$

In general, the value of the coverage factor *K* is chosen on the basis of the desired level of confidence to be associated with the interval defined by $U = Ku_c$. Typically, *K* is in the range 2 to 3. When the normal distribution applies and u_c is a reliable estimate of the standard deviation of *y*, $U = 2\ u_c$ (i.e., $K = 2$) defines an interval having a level of confidence of approximately 95 %, and $U = 3u_c$ (i.e., $K = 3$) defines an interval having a level of confidence greater than 99%.

The combined standard uncertainty $Uc(y)$ is used to express the uncertainty of many measurement results, Combined uncertainty for different errors of our experiment means the standard uncertainty for errors: due to the detector, thermal treatment, reader, evaluation procedure and over all response.

RESULTS AND DISCUSSION

A-TL RESPONSE

The TL response is measured with a Harshaw 4500 Reader using the planchet heating method. The sample is heated in contact with a stainless steel crucible; the temperature is controlled by a thermocouple placed in close contact with the sample holder. After irradiation, the sample is heated with a linear ramp of about 1.5 °C/s from 50 °C to 500 °C. This procedure ensures the complete reset of the films, so that no additional annealing stage is needed [4]. The TL response is the integral of the glow curve between 50 °C and 500 °C divided by the temperature rate. The dosimetric characterization has been performed with ^{60}Co photons from Cobalt therapy Unit, at the National Research Center, Atomic Energy Authority, Cairo, Egypt. The dose has been evaluated according to the IAEA code of practice [6, 7], with accuracy of 2.5%. For the irradiation with photon beams, the finger is placed in the same phantom at a 5 cm water-equivalent depth for ^{60}Co with source to skin distance (SSD), respectively, of 80 and 95 cm, the field was $10 \times 10\ cm^2$.

B-DETERMINATION OF THE UNCERTAINTY OF (LDPE-G-P (AAM/AAC)) DOSIMETERS

According to reference [3], technical recommendations for the use of thermoluminescence for dosimetry in individual monitoring for photons and electrons from external sources, a list of commonly encountered sources of errors that affect the precision and accuracy in determining the dose under geometrical conditions can be identified. The errors may result from the detectors, reader, thermal history and the photon- sensitivity of the detector to [8].

Table 1 shows the different uncertainty components of the detector for (LDPE-g-p (AAm/AAc)) film. The largest value of uncertainty (0.3 nC) was due to the contamination of TLD-materials.

Table 1

Errors due to the detector

Serial No.	Source of uncertainty	Value (nC)	Probability distribution	Divisor	C (nC)	Us (nC)	Us^2 (nC)^2
1	Transparency and other optical properties	0.015	Rectangular	$\sqrt{3}$	1	0.009	0.000081
2	Room temperature	0.055	Rectangular	$\sqrt{3}$	1	0.032	0.001024
3	Light effect	0.02	Rectangular	$\sqrt{3}$	1	0.012	0.000144
4	Energy dependence of dosimeter response	0.08	Rectangular	$\sqrt{3}$	1	0.05	0.0025
5	Contamination of TLD material	0.04	Rectangular	$\sqrt{3}$	1	0.02	0.0004
6	Ineffective cleaning procedure on detector	0.02	Rectangular	$\sqrt{3}$	1	0.012	0.000144
7	Variability of the mass of the TLD material in the detector	0.03	Normal	2	1	0.015	0.000225
8	Powder distributions in the tray of the reader	0.03	Normal	2	1	0.015	0.000225
9	Changes in the detector sensitivity due to the radiation damage	0.04	Rectangular	$\sqrt{3}$	1	0.017	0.000289
10	Repeatability	0.01	Normal	1	1	0.01	0.0001
11	The same irradiated surface on the tray	0.023	Rectangular	$\sqrt{3}$	1	0.013	0.000169

$Us = \sqrt{0.1636} = 0.0818$ nC;

$U = Us \times 2 = 0.17$ nC (at 95% confidence level).

Table 2 shows the different errors due to the reader and evaluation procedure. The readings must be normalized to the light source and PMT noise, because the uncertainty component has great value even if normalized.The expanded uncertainty is 0.192 nC. The largest value of the uncertainty was due to the light source which has the value 0.16 nC. The readings must be normalized to light source before counting.

Table 2

Errors due to the reader and the evaluation procedure

Serial No.	Source of uncertainty	Value (nC)	Probability distribution	Divisor	C (nC)	Us (nC)	Us^2 $(nC)^2$
1	PMT noise	0.11	Triangular	$\sqrt{6}$	1	0.045	0.002
2	Light source	0.17	Triangular	$\sqrt{6}$	1	0.07	0.0049
3	Time readings of the detectors after irradiation	0.14	Triangular	$\sqrt{6}$	1	0.057	0.0033

$Us = \sqrt{0.0102} = 0.1$ nC ;
$U = Us \times 2 = 0.2$ nC.

Table 3 shows the different errors due to the thermal treatment. The annealing process is a very important factor. The expanded uncertainty equals 0.04 nC. Among the errors due to thermal treatment, the annealing process gave the largest uncertainity, of 0.05 nC. The annealing must be achievable after each irradiation.

Table 3

Errors due to the thermal treatment

Serial No.	Source of uncertainty	Value (nC)	Probability distribution	Divisor	C (nC)	Us (nC)	Us^2 $(nC)^2$
1	Annealing	0.05	Triangular	$\sqrt{6}$	1	0.02	0.0004
2	During readout	0.03	Triangular	$\sqrt{6}$	1	0.012	0.000144

$Us = 0.024$ nC;
$U = Us \times 2 = 0.048$ nC.

Table 4 shows the different uncertainty components, observed over response curve that may be attributed to electrons originating in the radiation source holder and the surrounding air that are scattered in the TLD material. However, for higher energy gamma dose, many electrons can penetrate the TLD, resulting in a great dose, this effect will also be observed with any dosimeter that has small sensitive volume surrounded by a thin wall [11].

Gamma dose detectors have small dimensions compared to the range of the most energetic secondary electron that can exhibit over response errors when exposed in broad beam conditions. The TLD over response is appreciable for gamma rays greater than 0.66 MeV. Also, the over response decreased with increasing TLD thickness over response. The expanded uncertainties for cobalt-60 irradiation were 0.193 nC.

Table 4

Errors due to over response of TLD

Serial No.	Source of uncertainty	Value (nC)	Probability distribution	Divisor	*C* (nC)	*Us* (nC)	*Us*² (nC)²
1	Several holders	0.05	Normal	2	1	0.025	0.000625
2	Distance away from the source	0.07	Normal	2	1	0.035	0.00123
3	Several radionuclides	0.12	Normal	2	1	0.06	0.0036
4	Effects of beam size	0.14	Normal	2	1	0.07	0.0049
5	TLD size	0.02	Normal	2	1	0.01	0.0001

Us = 0.1022 nC;
$U = Us \times 2$ =0.21 nC;
Uc for all in all types of errors = 0.17 nC + 0.048 nC + 0.21 nC + 0.2 nC = 0.628 nC.

This implies that this value of uncertainty reading 0.628 nC should be added to the value of TL measurements every dose reading to make a correction of reading to obtain an accurate measured dose value.

CONCLUSIONS

Our results indicate that the radiation-induced graft copolymerization of binary monomer system acrylic acid/acrylamide (AAc/AAm) (50/50) onto low density polyethylene (LDPE) films is preferable to measure gamma dose due to its good compatibility with ionization chamber reading. The TL response of the new set of grafted polymer samples satisfies many of the requirements necessary for off-line dosimetry. Also, according to the results, it could be concluded that when gamma dosimeter such as (LDPE-g-p (AAm/AAc)) is used for measurements of the absorbed gamma dose, attention must be paid to the different uncertainty components. The combined uncertainty value in measurements including uncertainty value due to the detector errors, reader and evaluation procedure, thermal treatments and errors due to over response should be added to the value of dose measurements to characterize the accuracy of the dose reading value. Because the total uncertainty has a negligible contribution to the initial dose, the phosphorus presents good TL properties making it suitable for dosimetric application for ionizing radiation as well as for X and gamma radiation.

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