RESEARCH ON FADING CHARACTERISTICS OF ALANINE/ESR DOSIMETERS IN HIGH DOSE RANGE*

Chen Lishu (陈丽姝)

(China Institute of Atomic Energy, Beijing 102413, China)

H.Tachibana and Y.Haruyama

(Japanese Atomic Energy Research Institute, Takasaki, Japan)

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ABSTRACT

The present work has dealt extensively and systematically with the fading characteristics of polystyrene–alanine dosimeters irradiated at different dose rates and total doses under various temperatures (10— 70 °C) and stored a period of time in different conditions (5, 25, room temperature, 40 °C). Detail investigation on this effect in practical irradiation condition is very important. Because it is difficult to correct this effect using correction coefficients so far. So the temperature coefficients and fading rates have been given along with a lot of experimental data to try to make approximation of radical formation or decay behavior.

Keywords: Radiation processing dosimetry PS–alanine dosimeter ESR Transfer dosimeter Temperature coefficients Fading behaviour

1 INTRODUCTION

At present the standardization of high–dose dosimetry is the most important in the field of radiation processing where various kinds of dosimetry have been used, which generally includes both traceability to national, international or regional standard and timely calibration. These traceabilities are only achieved by some particular transfer dosimeters provided which are capable of giving sufficiently accurate and precise absorbed dose values in the transfer process of radiation quantities. Acording to the summing–up, advice and suggestion of IAEA advisory group on high–dose measurement, among the available methods alanine/ESR dosimetry system has many merits and is a suitable method used for routine dosimetry and transfer dosimetry for gamma–ray radiation processing. Many affecting factors have been investigated. However, in consideration of application to transfer dosimetry, the temperature effect is one of important factors which may exist in irradiation period, storage time and transport process. The effect has practical importance can not be avoided but be controlled and corrected. The present work has been conducted to investigate the fading characteristics of polystyrene alanine

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dosimeters irradiated at three different doses and dose rates with various irradiation temperature (10, 25, 40, 50, 60 and 70 °C) after a period of time stored in different conditions (5, 25, room temperature and 40 °C). A part of results from all the experimental data are reported here in .

2 EXPERIMENTAL METHODS

The work was completed in four parts: calibration of radiation field, irradiation and storage of sample dosimeters and then the evaluation of dose values.

2.1 Calibration of radiation field in terms of exposure

The gamma-ray irradiation of dosimeters were carried out using the newly developed standard dosimetry and irradiation system for high-dose dosimetry. A ^{60}Co slab source giving exposure rate ranging from 7.095 C/(kg · h) to 330 C/(kg · h) was used. The distributions of dose rate on the central axis crossing the centre of the source plane have been carefully calibrated using a secondary standard parallel plate ionization chamber in terms of exposure which had been timely calibrated in a standard ^{60}Co radiation field in ETL.

For studying irradiation temperature effect an accurate controlled sample box was prepared. The temperature and relative humidity inside the box range from 5 to 70 °C and from 30 % to 90 % respectively. Their uncertainties are ± 0.1 °C and ± 1 % of relative humidity. The movable distance from the sample box to the source ranges from 20 to 185 cm and can be adjusted within an accuracy of ± 0.1 mm. Non-uniformity of the radiation field within the physical dimension of dosimeters was found to be negligible.

The overall uncertainty in determining exposure rates in the radiation field is less than ±2 %[1].

2.2 Irradiation and storage techniques of sample dosimeters

Each sample dosimeter was contained in a polystyrene cylindrical holder with a wall of 4 mm. Each batch of five pieces of sample was irradiated simultaneously to 1.0×10^5, 1.0×10^4 and 1.0×10^3 Gy. Before irradiation these sample dosimeters had been put in the irradiation room waitting for two hours establishing a temperature equilibrium. All of irradiations were completed in the same way.

For accurately studying the effect of irradiation temperature on the concentration of free radicals induced in dosimeters, all of the initial measurements were conducted immediately as fast as possible after irradiation. However, it requires ten minutes only for irradiation temperatures more than 40 °C.

Storage of irradiated dosimeters: For studying the storage effect, the irradiated dosimeters were kept in two boxes with constant temperature of 25 °C and 40 °C respectively, and at room temperature as well as in a refrigerator for desired time interval. After the storage, these dosimeters were brought into the ESR spectrometer room with a constant temperature of 20±0.5 °C and a relative humidity of 50±2 % for evaluating dose values.

2.3 Dose evaluation

All the measurements of the dose response were made using a compact ESR reader[2] for the free radical dosimeters. Relative dose values are automatically read out in a few seconds with a precision of about ±1 %. In this relative measurement, the important thing is the stability of the sensitivity of the compact reader. To correct the change in the sensitivity with time, it was timely checked before and after every group of measurements by three reference dosimeter samples which were exposed to doses of 10^3, 10^4 and 10^5 Gy at the highest metrological quality. This procedure has significantly reduced the influence of affecting factors.

Each data point on these figures represents a mean value of five dosimeters irradiated simultaneously. The coefficients of variation are less than 1 %. The relative standard deviations of 10 measurements for the same dosimeter are within 0.5 % or so.

3 RESULTS AND DISCUSSION

Results selected from all the experimental work (Table 1) are reported as follows along with short analyses.

Table 1

Outline of the experimental conditions completed °C

Dose rate 7×10^3 Gy/h									Dose rate 1.0×10^3 Gy/h		
T.D.	1.0×10^5 Gy		T.D.	1.0×10^4 Gy		T.D.	1.0×10^3 Gy		T.D.	1.0×10^4 Gy	
I.T.	S.T.	No.	I.T.	S.T.	No.	I.T.	S.T.	No.	I.T.	S.T.	No.
10	25, 40	each 5	10	25, 40	each 5	10	25, 40	each 5			
25	5,25,40	each 5	25	5,25,40	each 5	25	25,40	each 5	25	5,25,40	each 5
40	5	5	40	5,25,40	each 5	40	5	5	40	5,25,40	each 5
70	5,25,40	each 5	60	25	5	70	5,25,40	each 5	60	5,25,40	each 5
70	5,25,40	each 5									

T.D.: Total dose I.T.: Irradiation temperature S.T.: Storage temperature No.: Number of sample

3.1 The effect of temperature during irradiation on the response of polystyrene alanine dosimeters

In order to obtain accurately, the temperature coefficients of responses, all the measurements were conducted immediately as fast as possible after irradiation except for irradiation temperature more than 40 °C. The result shows that the relative response of the dosimeters is found to increase with irradiation temperature (see Table 2). The result indicates that the values of temperature coefficient $((\triangle s/s)/°C)$ have no significant difference each other. The coefficient can be characterized by a mean value of (0.24±0.01) %/°C.

3.2 Fading characteristics for irradiation temperature 25 °C and different storage temperatures and total doses

The fading of the dose response is defined here as the percentage change in the response with time after irradiation compared with the original value. Fig.1–3 show that the fading behaviour depends on total dose and most of the fading appears within first 10 days. After the decay of short life-time radicals the response reduced very slowly and nearly stable for long time. With the storage time of 30 days the reduction is less than 2 % of the initial value after immediately irradiation, whereas under a storage temperature of 40 °C the reduction of the response may reach 4 %, after that there is no significant fading. The fading is about 5 % for a total dose of 10^5 Gy.

Table 2

Effect of temperature during irradiation on relative response of "AMINOGRAY" dosimeters*

Tatal dose/Gy	I.T. /°C	Mean values measured	Rel.Res.	T.C./ %·°C^{-1}
10^3	10	$1.054\times10^3\pm0.0005$	0.9431	
	25	$1.1176\times10^3\pm0.0072$	1.0000	
	40	1.1444×10^3	1.0240	
	70	$1.2212\times10^3\pm0.0009$	1.0927	0.25
10^4	10	$1.3762\times10^4\pm0.0109$	0.9543	
	25	$1.4344\times10^4\pm0.0124$	1.0000	
	40	$1.4503\times10^4\pm0.0078$	1.0110	
	50	1.4826×10^4	1.0336	
	60	1.5201×10^4	1.0598	
	70	$1.5753\times10^4\pm0.0046$	1.0982	0.23
10^5	10	$1.4498\times10^5\pm0.0058$	0.9501	
	25	$1.5259\times10^5\pm0.0032$	1.0000	
	10	1.5130×10^5	1.0112	
	70	$1.6688\times10^5\pm0.0024$	1.0936	0.24

* Exposure rate = 182 C/(kg · h) I.T.: Irradiation temperature T.C.: Temperature coefficient

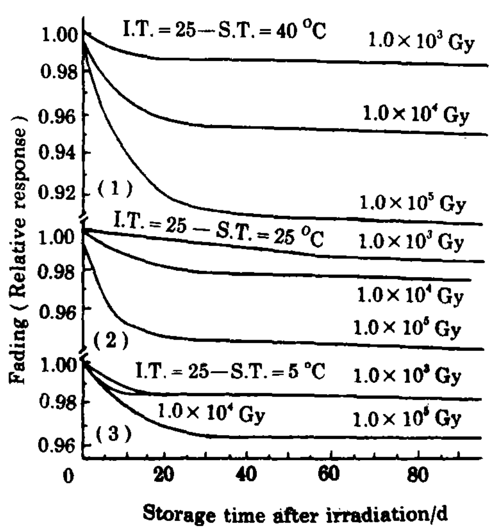

Fig.1— 3 Fading characteristics of alanine/ESR dosimeter at irradiation temperature 25°C and different storage temperature

So far as the total dose of 1.0×10^4 Gy is concerned. The fadings for 30 d are 1.6, 2 and 4.5 %, respectively for storage temperatures 5 (in refrigerator), 25 and 40 °C. The fading increases with storage temperature.

3.3 Fading characteristic for different storage temperatures and different irradiation temperatures at the same irradiation dose

Fig.4— 6 show the effect under the same total dose of 1.0×10^4 Gy. The first-stage fadings are 1.6, 3 and 5.4 % respectively for storage temperatures of 5, 25 and 40 °C

irrespectively of irradiation temperature. This suggests keeping the dosimeters in refrigerator. Regardless of irradiation and storage temperatures the first-stage decay of short life-time radicals is less than 5 % for the total dose of 1.0×10^3 Gy.

3.4 Comparisons between high irradiation temperature with low storage one and low irradiation temperature with high storage one

Fig.7— 8 show that the first-stage fadings are less than 1.5 % for storage temperatures of 5 °C and 25 °C (see Fig.5), whereas it is 3.5 % for storage temperature 40 °C. Fig.7 indicates a fading characteristic under the high storage temperature of 40 °C. Both curves for total doses 10^4 and 10^5 Gy show large decays more than 3 % in the first stage.

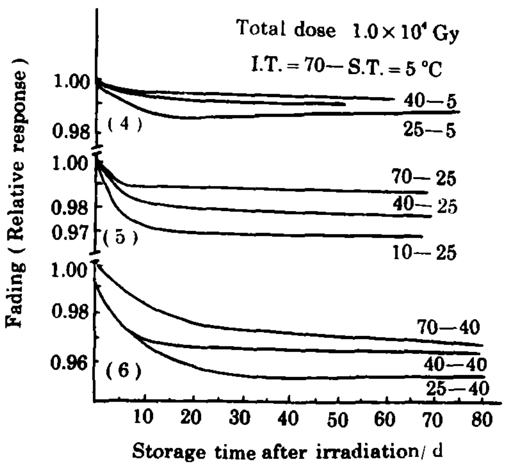

Fig.4—6 Fading characteristics of alanine/ESR dosimeters at different irradiation temperatures and storage temperatures

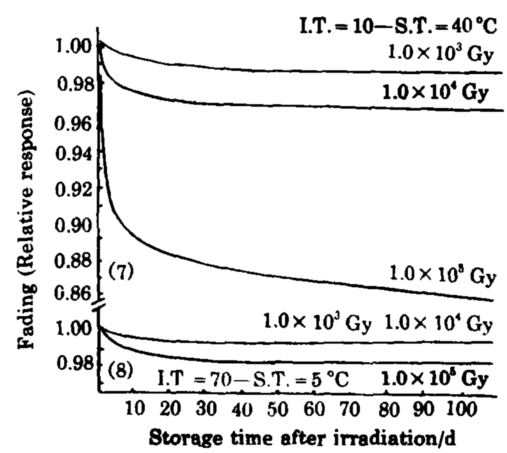

Fig.7—8 Fading characteristic under irradiation at 70 °C and storage at 5 °C, as well as under irradiation at 10 °C and storage at 40 °C

3.5 The first decay for low total dose

The first decay above mentioned is less than about 1 % for low total dose of 1.0×10^3 Gy, at all the irradiation and storage conditions. After the first decay the reduction is so slow that we can neither find further decay in several monthes nor compare exactly it with previous results obtained by Dr. Kojima under elevated temperature up to 150 °C[2].

3.6 Comparisons between high and low irradiation temperature for high dose

It is shown from Fig.8—10 that the first-stage decay theory is observed for short time after irradiation under high doses. The first decay component of the initial response increases with decreasing irradiation temperature. If the difference between irradiation and storage temperatures is identical values, then the second-stage fading has roughly similar tendency.

3.7 Largest first fading

Among all of experimental results the largest first fading appears in the cases of the highest storage temperature of 40 °C, the highest dose of 1.0× 10^5 Gy and the lowest irradiation temperature of 10 °C (see Fig.1,7,11).

3.8 Effect of dose rates on fading

The fading does not depend on dose rates for two different values (see Fig.12).

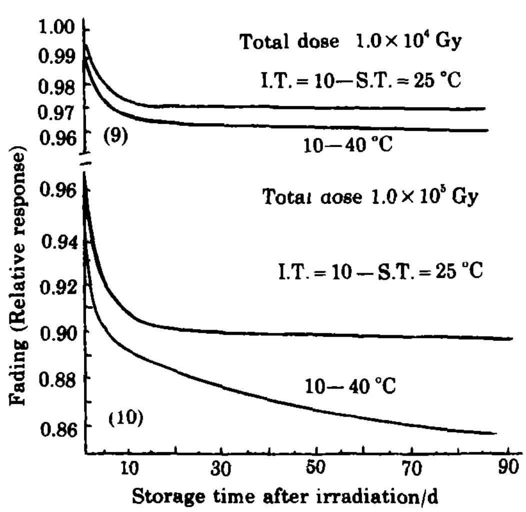

Fig.9— 10 Fading characteristics under low irradiation temperature for different total doses

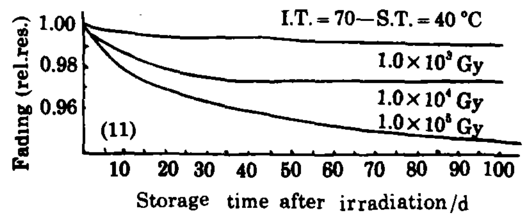

Fig.11 Fading characteristics under high storage temperatures for different total doses

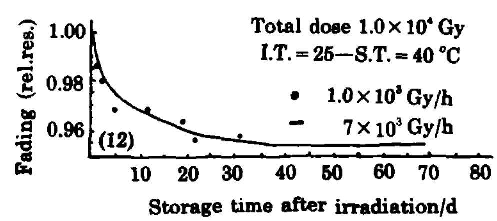

Fig.12 Fading characteristics under two dose rates

4 CONCLUSION

Taking account of dosimetric factors such as temperatures during irradiation and storage as well as total doses, we come to following conclusions.

a. The temperature coefficients of the dose response do not depend on the irradiation and storage temperature as well as total doses covered in this experimental work.

b. The results indicate that a two-step process exists in the fading of the dosimeter response. It may be used to support the argument about two-stage decay theory in the fading of induced free radicals[4,5].

c. The fading rate of the dosimeter response within a storage time is only 2 % of the initial value immediately after irradiation with a total dose of 1.0× 10^4 Gy, the irradiation temperature of 25 °C and 30 days of storage time at room temperature.

Whereas the fading rate is about 4 % under a storage temperature of 40 °C. After the first-stage fading, the response becomes very stable without further fading. These characteristics will make the polystyrene alanine dosimeter useful for industrial radiation processing and testing. The suitability of this kind of alanine dosimeters used for transfer dosimeter in industry is evident from these results.

d. The wide irradiation and storage temperature range was covered in this dosimetric work. This suggests that the polystyrene alanine transfer dosimetry system is applicable to a wide region of Asian countries with a wide variation of environmental temperature.

5 WORK IN FUTURE

Type and concentration of free radicals formed by ionizing radiation generally depend on the crystal structure of alanine and the temperaure. The characteristics of the decay and formation of the free radicals could be explained by more detailed analysis of the ESR spectrum. At present, however, few data about these basic chemical mechanism are available. It would be of great interest if such fading characteristics mentioned could be explained based on the knowledge about generation and decay kinetics of radiation inducing radicals. It is believed that in near future some progresses will be made in research of generation and disappearing of free radicals. This will pave the way for an adequate explanation of fading behaviour of alanine/ESR dosimeters.

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