ARE/AEE./[redacted] Rep. — 256

ARAB REPUBLIC OF EGYPT
ATOMIC ENERGY ESTABLISHMENT
RADIATION PROTECTION DEPARTMENT

DOSIMETRIC ENERGY RESPONSE OF $CaSO_4$: DY THERMOLUMINESCENCE DOSIMETERS TO ALPHA PARTICLES

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CONTENT

ABSTRACT

The main aim of the present experimental investigation is to study the dosimetric energy response of $CaSO_4$: Dy thermoluminescence dosimeter to alpha particles. For proper estimation of the dose absorbed by the dosimeter, the alpha particle fluence must be measured. In order to do so, CR-39 plastic track detector is used. Experimental results indicated that $CaSO_4$: Dy dosimetric response to alpha particle is not only function to the alpha particle energy but also to the emission rate of the source.

INTRODUCTION

Among the commercial thermoluminescence dosimeters, Ca SO_4: Dy is the most sensitive TLD and it exhibits considerably less fading than other TLDs as recommended by Becker (1972)[1] and the present work results. Recently Vohra et al (1980)[2] developed a presonnel dosimeter TLD badge based on home made Ca SO_4 : Dy Telfon TLD discs.

It is the aim of the present study is to throw some light on the energy response of Ca So_4 : Dy to alpha particles. Barlett and Edwards (1979)[3] reported the light conversion efficiency of TLD-700 for alpha particles relative to Co-60 gamma radiation. For the measurements of the dose to the basal layer of the epidermis from alpha active material near the skin surface, Harvey and Townsend[4]) used lithium fluoride. Solid state nuclear track detector were used by Malik and Alwor-Fali[5]) for alpha particle dosimetry and by Abu-Jarad and Fremlin[6]) to study the air borne alpha activity inside houses and to study its emanation from different materials. In the present study CR-39carbonate plastic track detector is used for alpha particle fluence estimation hence for absorbed dose rate estimation received by the thermoluminescence dosimeter.

PRELIMINARY WORK

Several TL dosimeters such as TLD-100, TLD-200, TLD-400, TLD-600, TLD-700, TLD-800 from Harshow chemical company and ^{7}LiF teflon discs from Teledyne are in use in our laboratary for dosimetric measurements. The details given by the TLD manufactures are reported in Table 1.

Table 1.

Solid Thermoluminescence dosimeters

Material	Manufac- turer	Physical form	Dimensions	Remarks
LiF TLD-100	Harshow	crystal	3x3x1 mm^3	7.5% ^{6}Li, 92.5% ^{7}Li
LiF TLD-700	"	"	"	0.01% ^{6}Li, 99.99% ^{7}Li,
LiF TLD-600	"	"	"	95.62% ^{6}Li, 4.33% ^{7}Li,
LiF [illegible]-7	Teledyne	Teflon disc	9mmØ;0.4m thick.	6% phosphor
CaF TLD-400	Harshow	crystal	3x3x1 mm^3	
$CaSO_4$ TLD-200	"	"	"	$CaSO_4$: Dy

The dosimeters under study (except LiF-7 Teflon disc) were annealed at 400 °C for 24 hours, LiF-7 Teflon discs dosimeters were taken from a new batch and it was annealed at 300°C for one hour, in order to remove the natural backgrond radiation effects.

For TL measurements, the Harshow 2000 (A+B) system was used where the heating time lasts 30 seconds, the maximum tray temperature was 240°C (in order to reduse the background noise). The heating rate was estimated to be around 8.5°C/second from 50°C to 240°C, hence, the tray temperature was constant at 240 °C for 7.5 seconds,

1. Response to Gamma rays

In table 2 the sensitivity of the used dosimeters exposed to 6.2 rad gamma rays is reported. In the same table the relative sensitivity is included.

Table 2.

Sensitivity of the used dosimeters to Gamma rays

Dosimeter	TL signal in nC	Relative sensitivity nC/mGy
LiF TLD-100	8.8	0.14
CaSOTLD-200	433.2	6.99
CaF TLD-400	172.5	2.78
LiF TLD-600	17.7	0.28
LiF TLD-700	12.0	0.19
LiF-7 teflon	2.0	0.03

It is clear from table 2 that TLD-200 ($CaSO_4$:DY) has the highest response to gamma rays while LiF-7 Teflon disc has the least response to gamma rays. Due to its high sensitivity to gamma rays $CaSO_4$: Dy was recommended for environmental radiation monitoring. The second quality of this dosimeter is its poor fading property (1.5% during 6 weeks at 30°C).

In table 3, the variation of the TL signal of $CaSO_4$: Dy with exposure time is reported

Table 3.

Variation of TL signal due to Cs-137 source inside TLD calibrator with exposure time.

Exposure time	TL signal nC
30 s	19.7
60 s	41.2
2 m	89.9
5 m	214.7
10 m	421.9
20 m	779.0

From the results shown in table 3 it is clear that the relation between TL signal and exposure time (t) is as follows

$$\text{TL signal (nC)} = (0.693 \pm .029)\, t\ (s)$$

For reproducability studies, TLD-200 dosimeters were exposed to Cs- 137 gamma rays for one minute and the results are presented in table 3a.

Table 3a

Gamma ray reproducesbility results for $CaSO_4$: Dy TLD exposed to 6.2 mGy

Dosimeter No	TL signal in nC	
	Fresh	old
1	41.2	38.5
2	42.2	34.9
3	38.9	35.0
4	37.3	35.3
5	—	38.5
average	39.9 ± 1.8	36.4 ± 1.6

From the results shown in table 3a it is clear that for fresh TLD the response to gamma rays is 6.44 ± 0.29 nC/mGy and it is for old TLD-200 dosimeters is 5.85 ± 0.26 nC/mGy.

The uncertainty of the dosimeter Q is evaluated by the following

$$Q = \sum_{i=1}^{n} \frac{Q_i}{n}$$

where $Q_i = \left| \frac{\bar{P} - P_c}{P_c} \right| 100$

$\bar{P}$ is the mean of a set of measurements.

$\bar{P} = \frac{1}{n} \sum_{i=1}^{n} P_m$, P_c is the dosimeter TL signal.

2. Response to alpha particles

For the measurements of the relative reponse of the dosimeters under consideration to alpha particles, Am-241 source was used. The TLD dosimeters were placed in contact with the source (in turn) so that the exposure time was one minute only. The time elapsed between the end of irradiation and the TL signal measurements was adjusted to be 30 seconds. Experimental results are shown in Table 4.

Table 4.

Response of TL dosimeters to Am-241 radiations

Dosimeter	TL signal nC	Dosimeter	TL signal nC
TLD-100	3.451	TLD-600	6.8
TLD-200	400.24	TLD-700	4.558
TLD-400	68	TLD-700 Teflon	0.384

From the results reported in Table 2 and Table 4 it is clear that $CaSO_4$: Dy has the highest response not only to gamma rays but also to alpha particles relative to the used thermoluminercence dosimeters. For the proper estimation of the dosimetric energy response of Ca SO_4 : Dy to alpha aprticles the following experiments were done.

3. Alpha Particle fluence rate measurements

For alpha particle fluence rate measurements, CR-39 carbonate plastic detector was used. The plastic detectors were supplied from Amerian Acrylic and the samples dimensions were 2x2x0.1 cm^3.

The plastic detectors are etched after irradiation to alpha particles in 30% NaOH solutions for one hour at 70°C. In order to reduce background radiations the plastic detectors are usually covered by 5 mg/cm^2 polyethylene sheets before and after irradiation.

Optical research microscope was used for track density estimation.

Several alpha-particles sources were used in the present study namely U-235, and Am-241 sources.

In table 5, the variation of track density with exposure time (0.5-3 minutes) is reported, where the CR-39 detectors were brought in close contact with the U-235 source.

Table 5

Variation of track density with exposure time for U-235

Exposure time	Track density in tracks / cm^2
½ minute	45112 (± 10.5%)
1	91967 (± 7.7%)
2	174000 (± 6.0%)
3	254900 (± 4.6%)

From table 5, it is clear that the emission rate of the U-235 source is 1400 ± 88 tracks / cm^2.s.

For production of alpha particles with energies less than 4.68 MeV (U-235 alpha particle energy) the separation distance between the U-235 and CR-39 detectors in air at 15°C was varied up to 2.5 cm.

In table 6, the variation of the recorded track density with separation distance in air is reported where the exposure lasts one hour for each case.

Table 6

Vairation of track density with separation distance from U-235 source in air.

Distance in cm	alpha particle energy in MeV	track density tracks/cm^2.h
0	4.68	5.04×10^6 ($\pm$ 6%)*
1.0	3.7	4.34×10^5 ($\pm$ 7%)
1.5	3.0	1.4×10^5 ($\pm$ 6%)
2.0	2.2	6.4×10^4 ($\pm$ 8%)
2.5	1.5	3.1×10^4 ($\pm$ 10%)

* estimated from the results reported in the last table.

For estimation of the alpha particle energy the range-energy relationship of alpha particles in air was used after Evans[7]) since CR-39 responds to alpha particles with 100% efficiency, hence the tracks/cm^2.h results are the fluence rate results.

For the Am-241 source, several attempts were made to estimate alpha particle fluence rate using Cr-39 carbonate plastic detectors when the source is in close contact with the detector, yet all trails were failed and the exposure time should be much less than 2 seconds.

Yet using TLD-200 thermoluminescence dosimeters at 35cm from the source, activity is estimated to be around 0.638 mCi (2.36×10^{7} Bq). Where the following factors were taken into considerations:-

1- The response of TLD-200 to keV photons is five times its response to Cs-137 photons, after Vohra et al[2]).

2- The exposure rate of Am-241 at one meter per Ci is 10^{-2} mR/h (7.1×10^{-8} A/kg after Vallario[8]).

The Am-241 source area was estimated from alpha radiography and it is found to be 0.264 cm^2. From the previous results the fluence rate of the source is estimated to be 4.0×10^{7} alpha particle per cm^2 per second, where the source yield was taken as 10^{6} alpha per min. /Ci after the radio chemical centre Manual (1978).

4 - <u>Absorbed dose rate estimation</u>

For the estimation of the absorbed dose rate received by Ca SO_4 : Dy dosimeter during irradiation by alpha particles, the following relation is used.

$$D = \phi \frac{E \times 1.6 \times 10^{7}}{\rho \times R} \quad mGy.S^{-1} \qquad (1)$$

where D is the absorbed dose rate in mGy s^{-1}

ϕ is the fluence rate in cm^{-2} s^{-1}

E is the alpha particle energy in MeV.

ρ is the density of Ca SO_4 : Dy dosimeter and it is measured as 3.5 g/ml

R is the range of alpha particle in Ca SO_4:Dy $4.62 \times 10^{-4} R$ air (after dragu[9]).

where R_{air} is the range of alpha particle in air.

From the previous results reported in table 6 and relation (1) , the variation of the absorbed sose rate received by $Ca\ SO_4$: Dy dosimeter with the separation distance in air is tabulated in Table 7.

Table 7

Variation of absorbed dose rate with separation distance from U235 source.

separation distance	alpha particle energy in MeV	estimated absorbed dose rate in mGy/h
in contact	4.68 MeV	796 (± 6%)
1 cm	3.7 MeV	72.1(± 7%)
1.5 cm	3.0 MeV	24.3(± 6%)
2.0 cm	2.2 MeV	11.6(± 8%)
2.5 cm	1.5 MeV	6.6 (±10%)

5 - Dosimetric energy response of $Ca\ SO_4$: Dy dosimeter

For the proper estimation of the dosimetric energy response of $Ca\ SO_4$: Dy dosimeters to alpha particles, $Ca\ SO_4$: Dy dosimeters were placed in turn at various distances from the U-235 source, where the exposure time lasts 100 hours.

Since U-235 source not only emits alpha particles but also low energy photons, hence TL measurements were carried out with and without polyethylene sheet ($>$ 5 mg/cm^2).

Variation of the recorded TL signal with the separation distance from the source is reported in Table 8.

Table 8

Variation of TL signal with the separation distance in air from U-235 source.

separation distance in cm	particle energy in Mev	TL signal (nC) with shield	without shield	net due to alpha particles
0	4.68	91	2078	1987(± 4%)
1	3.7	15	110	175(± 4%)
1.5	3.0	9	49	40(± 5%)
2.0	2.2	5.6	15	9.4(± 7%)
2.5	1.5	4	6	2 (±15%)

From the previous results reported in Table 7 and table 6 the dosimetric energy response of alpha particles is estimated for alpha particle energies from 4.68 down to 1.5 Mev and it is found as reported in Table 9.

Table 9

Dosimetric energy response of TLD-200 for alpha particles

Energy in MeV	dosimetric response nC/mGy	relative to γ-rays
4.68 MeV	025 (7.2%)	4.1×10^{-3} (± 0.2%)
3.7 MeV	.024(+ 8%)	3.9 (± 9.5%)
3.0 MeV	.016(7.8%)	2.6 (8.76 %)
2.2 MeV	.008(13%)	1.3 (13.6 %)
1.5 MeV	.003(18 %)	0.5 (18.4 %)

For Am-241 sources, variation of TL signal with and without polyethylene shield (> 5 mg/cm^2) are reported in table 10, where the exposure time varies from one minute to 100 hours according to the separation distance and the results are normalized to one hour.

Table (10)*

separation distance in cm	alpha energy	TL signal in nc without shield	with shield	net
0	5.5 MeV	24000	194	23806
1.4	4.0	30.7	6.3	24.4
2.2	3.2	4.81	2.8	2.0
3.1	1.7	1.40	1.23	0.17
4.1	---	0.77	0.71	.06
5.1	---	0.49	.49	---

x Vairation of TL signal recorded in TLD-200 with the separation distance from Am-241 source.

From the previous results reported in table 9 and table 10 the estimated absorbed dose rate at various distances from the Am. 241 (due to alpha particles) is estimated.

Table 11

Estimation of the α - absorbwd dose rate in contrat and around Am-241 source.

particle energy	mGy/h x	mGy/h	Remark
5.5 MeV	10^6	$2.0x10^7$.	x estimated from results.
4.0 MeV	101	$2.2x10^4$..	. estimated from the source activity.
3.2 MeV	111	———	.. estimated from track measures.
1.7 MeV	42.5	5.3..	

where the range of Am-241 alpha particles is recently reported to be 4 cm by AKber - et al in air or (5.00± 0.06) mg/cm^2 by Thwaites[11]).

From table 11, it is clear that at low dose rate agreement is evident between the results obtained from TL measurements and track measurements, while of dose rate greater than 1 Gy/ hr the results obtained by TL measurements is much les than the results obtained by the track method. Hence, it is evident that Ca SO_4: Dy is absorbed dose rate dependent

6 - Conclusions

The present work experimental investigation may indicate the following features

1- Ca SO_4 : DY TLD has not only excellent properties for photons dosimetric measurements but also it is the most sensitive dosimeter for alpha particle dose estimation.

2 - CR-39 carbonate plastic detector is proven to be excellent alpha particle deteector provided that the alpha particle emission rate of the source is less than 10^6 alpha par ticles / cm^2 per second.

3 - It is evident from the present study that Ca SO_4 : Dy response varies from 4×10^{-3} at 4.5 MeV to 5×10^{-4} at 1.5 MeV relative to Cs - 137 γ -rays.

4 - Present work experimental results clearly indicates that Ca SO_4 : Dy detector is also absorbed dose rate dependent.

5 - Since alpha particle sources are widely used in research institutes and universities, hence, basic radiation protection measures must be applied carefully and it must be noticed that the gamma ray surface absorbed dose is estimated to be 6.7 mGy/h for Am-241 and for U-235 source it is 0.03 mGy/h. While the surface absorbed dose due to alpha-particle is around 400 Gy/ min. for Am-241 and for U-235 is around 0.8 Gy/hour.

6 - Thin sheets of Ca SO_4 : Dy crystals may prove to be the ideal alpha particle dosimeter.

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