FIRST INTERNATIONAL MEETING ON APPLIED PHYSICS
420 Badajoz, Espanha 13-18 Outubro 2003

PERFORMANCE OF DIFFERENT THERMOLUMINESCENT DOSEMETERS IN $^{90}Sr+^{90}Y$ RADIATION FIELDS

Mércia L. Oliveira and Linda V.E. Caldas

Instituto de Pesquisas Energéticas e Nucleares

Av. Prof. Lineu Prestes, 2242

05508-000 – São Paulo, SP – Brazil

RUNNING TITLE: TL DOSEMETERS FOR $^{90}Sr+^{90}Y$ DETECTION

PERFORMANCE OF DIFFERENT THERMOLUMINESCENT DOSEMETERS IN $^{90}Sr+^{90}Y$ RADIATION FIELDS

Mércia L. Oliveira and Linda V.E. Caldas

Abstract

The dosimetry of beta radiation is a difficult process specially because of the low penetration of beta particles in matter. The dosemeter utilized for this kind of procedure needs to approximate an ideal point-like detector: it should be as thin as possible, and its area should be small. The thermoluminescent dosemeters approach these requirement properties. The aim of this work was to study the dosimetric characteristics of different thermoluminescent dosemeters to verify the possibility of their use for the calibration of $^{90}Sr+^{90}Y$ plane applicators. The response reproducibility, calibration curves, TL response as a function of the source-detector distance, the transmission factors and the linearity of the sample response were obtained for several types of dosimetric pellets.

Introduction

Beta ray sources are widely used in brachytherapy specially for treatment of superficial lesions, as for example the $^{90}Sr+^{90}Y$ sources used in the post-operative treatment of pterygia. In these cases, plane or concave applicators can be used. The typical dose values are 8-10 Gy to the surface per brachytherapy section [1].

Plane sources can be accurately calibrated using an extrapolation chamber. In this case, the applicator is localized at 1 mm from the chamber entrance surface and the measurements are taken by varying the chamber depth. Using the extrapolation method, the absorbed dose rate at the applicator surface can be determined [2]. As an alternative method for the calibration of such beta applicators, and for concave plaques too, the use of calibrated relative dosemeters is recommended, such as thermoluminescent dosemeters, radiochromic films and diodes [3].

Thermoluminescent dosemeters (TLD) are usually applied for radiation detection. There is a variety of available TL materials, but the most popular is the lithium fluoride (LiF) because of its radiation absorption characteristics close to water, and of its easy reutilization [3]. Natural calcium fluoride (CaF_2) was the most important material on the early days of TL dosimetry; since the last decades, doped forms are most widespread, such as CaF_2-manganese and -dysprosium activated [4]. At the Instituto de Pesquisas Energéticas e Nucleares (IPEN), Brazil, $CaSO_4$:Dy pellets are routinely produced for radiation dosimetry. Pure and doped samples with different thickness and doping percentage are produced. The most indicated materials for beta radiation detection are thin pellets and those pellets doped with graphite [5-7].

The aim of this work was to study the dosimetric characteristics of LiF, CaF_2:Mn, CaF_2:Dy and $CaSO_4$:Dy (pure and doped) samples to verify the possibility of their use for the calibration of plane $^{90}Sr+^{90}Y$ applicators.

Materials and Methods

In this work, seven kinds of TL dosemeters were utilized. They are listed in Table 1. The samples were calibrated using a $^{90}Sr+^{90}Y$ source (109 MBq, 2003), Amersham Buchler, that has a calibration certificate from the German primary standard laboratory, Physikalisch-Technische Bundesanstalt (PTB). This source was calibrated at the distances of 11, 30 and 50 cm. The TL samples were irradiated on a special polymethyl methacrylate support (phantom), with 16 mm in thickness, covered by a plastic foil (Hostaphan) of 2.1 mg/cm^2 (surface density). The samples were exposed also to beta radiation from a $^{90}Sr+^{90}Y$ plane applicator (Amersham), 646 MBq (2003), on the same phantom, at the distance of 11 cm.

To determine the transmission factors, polyethylene terephthalate (Hostaphan) foils and acrylic plates with superficial densities, respectively from 1.04 mg/cm^2 to 38.5 mg/cm^2, and from 114.73 mg/cm^2 to 174.84 mg/cm^2 respectively, were utilized as absorber materials.

Prior to each irradiation, the TDL-100, TLD-200, TLD-400 and thin TLD-400 samples were thermally treated at 400°C during 30 min and all $CaSO_4$:Dy pellets were treated at 300°C during 3 h.

The TL measurements were taken on a Harshaw Nuclear System, model 2000A/B, with a linear heating rate of 6.5°C/s. The reading cycle was performed within 45s, with a constant flux of N_2 of 5.0L/min; the maximum temperature of 300°C was reached in each readout cycle in the case of $CaSO_4$:Dy samples. Light emission was integrated in the temperature interval between 50 and 350°C, within 50 s in the case of all other samples; the N_2 flux remained constant. The output data were recorded at a X-t register ECB, model RB-101, with two channels.

Results and Discussion

Reproducibility

The reproducibility of the TL response of the samples was obtained by their TL evaluation after 5 repeated procedures of standard annealing and irradiation with the $^{90}Sr+^{90}Y$ standard source at 11 cm. Results are shown in Table 2. The maximum percentual deviation was obtained for CaF_2:Dy (TLD-200): 9.2%. The best results were obtained for $CaSO_4$:Dy + 10%C (2.3%) and thin $CaSO_4$:Dy (2.8%).

Calibration Curves

The TL response of the samples as a function of absorbed dose was measured using the $^{90}Sr+^{90}Y$ standard source at 11 cm, in the dose interval of 1 to 70 Gy. Data are shown in Figures 1(a) and 1(b). The curves show their usefulness in the whole tested dose interval for all materials. The calibration curves of conventional and thin TLD-400 show a linear behaviour while the curves of TLD-100 and TLD-200 present supralinear characteristics. The $CaSO_4$:Dy pellets show a sublinear behaviour up to 10 Gy, and then the curves become supralinear.

TL Response as a Function of the Distance

The TL response of the samples was obtained varying the distance between the samples and the standard beta source. This distance was varied from 10 up to 30 cm. All samples present a similar decrease in their TL response, as shown in Figures 2(a) and 2(b).

Transmission Factors

Transmission factors were determined placing sheets of tissue equivalent materials between the source and the samples on the phantom. The transmission factors were defined as the ratios between the sample TL response measured with an attenuator (thickness a) and TL response extrapolated to absorber null thickness [8]. These transmission factors, shown in Tables 2 and 3, present an initial increase, and about 7 mg/cm^2 to 50 mg/cm^2 of tissue thickness, depending on the material, they initiate to decrease.

Measurements with a Plane Applicator

The linearity of the TL response was obtained using the $^{90}Sr+^{90}Y$ plane applicator. All TL samples were irradiated during 1, 2, 4 and 10 h. The results are shown in Figures 3(a) and 3(b). All materials present a suitable performance in all dose interval. The equivalence between irradiation time and absorbed dose can be obtained from Figures 1(a) and 1(b).

Conclusions

The results obtained show the usefulness of all tested materials for beta dosimetry. Due to the low penetration in matter of beta particles, the thinner dosemeters, as thin TLD-400, thin $CaSO_4$:Dy, and $CaSO_4$:Dy+10%C, proved to be more adequate than the conventional dosemeters for beta dosimetry.

Acknowledgements

The authors acknowledge Dr. L.L. Campos for providing the $CaSO_4$:Dy pellets, Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Brazil, for the partial financial support.

References

[1] Ali, M.M. and Khan, F.M. *Determination of surface dose rate from a ^{90}Sr ophthalmic applicator*, Med. Phys. **17** (3) 416-421 (1990).

[2] De Almeida, C.; Dewerd, L.; Järvinen, H. and Soares, C. *Guidelines for the calibration of low energy photon sources and beta-ray brachytherapy sources*, SSDL Newsletter **43** 4-25 (2000).

[3] International Commission on Radiation Units and Measurements. *Dosimetry of beta rays and low-energy photons for brachytherapy with sealed sources.* (ICRU Draft Report) (2001).

[4] Portal, G. *Review of the principal materials available for thermoluminescent dosimetry.*, Radiat. Prot. Dosim. **17** (1-4) 351-357 (1986).

[5] Campos, L.L. and Lima, M.F. *Thermoluminescent $CaSO_4$:Dy teflon pellets for beta radiation detection*, Radiat. Prot. Dosim. **18** (2) 95-97 (1987).

[6] Campos, L.L. *Graphite mixed $CaSO_4$:Dy TL dosemeters for beta radiation dosimetry*, Radiat. Prot. Dosim. **48** (2) 205-207 (1993).

[7] Daros, K.A.C.; Campos, L.L. and Medeiros, R.B. *TL response study of the $CaSO_4$:Dy pellets with graphite for dosimetry in beta radiation and low-energy photon fields*, Appl. Radiat. Isot. **54** (6) 957-960 (1990).

[8] Caldas, L.V.E. *Performance characteristics of an extrapolation chamber for beta radiation detection*, Appl. Radiat. Isot. 37 (9) 988-990 (1986).

Table 1 – Thermoluminescent materials utilized in this work.

Material		Dimensions
LiF	Harshaw TLD-100	$3\times3\times0.9$ mm^3
CaF_2:Dy	Harshaw TLD-200	$3\times3\times0.9$ mm^3
CaF_2:Mn	Harshaw TLD-400	$3\times3\times0.9$ mm^3
Thin CaF_2:Dy	Harshaw thin TLD-400	$3\times3\times0.25$ mm^3
Thin $CaSO_4$:Dy	IPEN	6.0 mm in diameter and 0.2 mm in thickness
$CaSO_4$:Dy + 10% C	IPEN	6.0 mm in diameter and 0.2 mm in thickness
Conventional $CaSO_4$:Dy	IPEN	6.0 mm in diameter and 0.8 mm in thickness

Table 2 – Reproducibility of the TL materials tested in this work.

Material	**Reproducibility (%)**
LiF (TLD-100)	5.1
CaF_2:Dy (TLD-200)	9.2
CaF_2:Mn (TLD-400),	4.5
Thin CaF_2:Mn (thin TLD-400)	5.1
$CaSO_4$:Dy (IPEN)	8.9
$CaSO_4$:Dy + 10%C (IPEN)	2.3
Thin $CaSO_4$:Dy (IPEN)	2.8

Table 3 – Transmission factors in tissue (dimensionless) for beta radiation ($^{90}Sr+^{90}Y$) using Harshaw TL dosemeters.

Tissue thickness		TLD-100	TLD-200	TLD-400	Thin TLD-400
(mm)	(mg/cm^2)				
0	0	1.000	1.000	1.000	1.000
0.02	2	1.069	1.139	1.095	1.102
0.04	4	1.102	1.203	1.147	1.149
0.05	5	1.111	1.213	1.162	1.160
0.07	7	1.125	1.217	1.174	1.171
0.10	10	1.127	1.191	1.172	1.160
0.20	20	1.081	1.115	1.120	1.092
0.50	50	1.014	1.044	1.008	1.027
1.00	100	0.910	0.931	0.880	0.960

Table 4 – Transmission factors in tissue (dimensionless) for beta radiation ($^{90}Sr+^{90}Y$) using $CaSO_4$:Dy pellets, produced at IPEN.

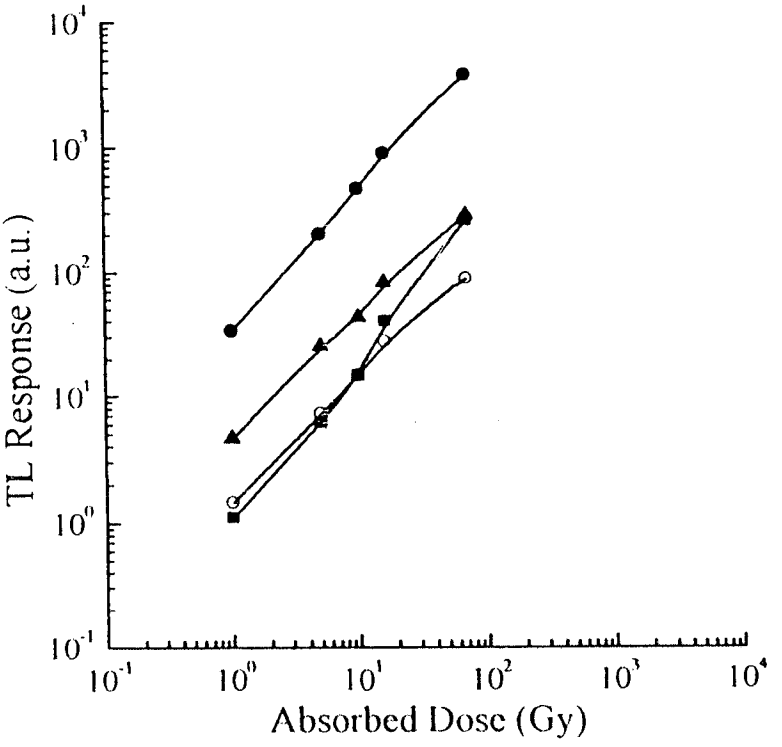
Tissue thickness (mm)	Tissue thickness (mg/cm^2)	Conventional $CaSO_4$:Dy	Thin $CaSO_4$:Dy	$CaSO_4$:Dy +10%C
0	0	1.000	1.000	1.000
0.02	2	1.020	1.070	1.038
0.04	4	1.038	1.094	1.074
0.05	5	1.042	1.100	1.090
0.07	7	1.051	1.112	1.114
0.10	10	1.062	1.123	1.142
0.20	20	1.061	1.140	1.194
0.50	50	1.004	1.122	1.214
1.00	100	0.908	1.000	1.074

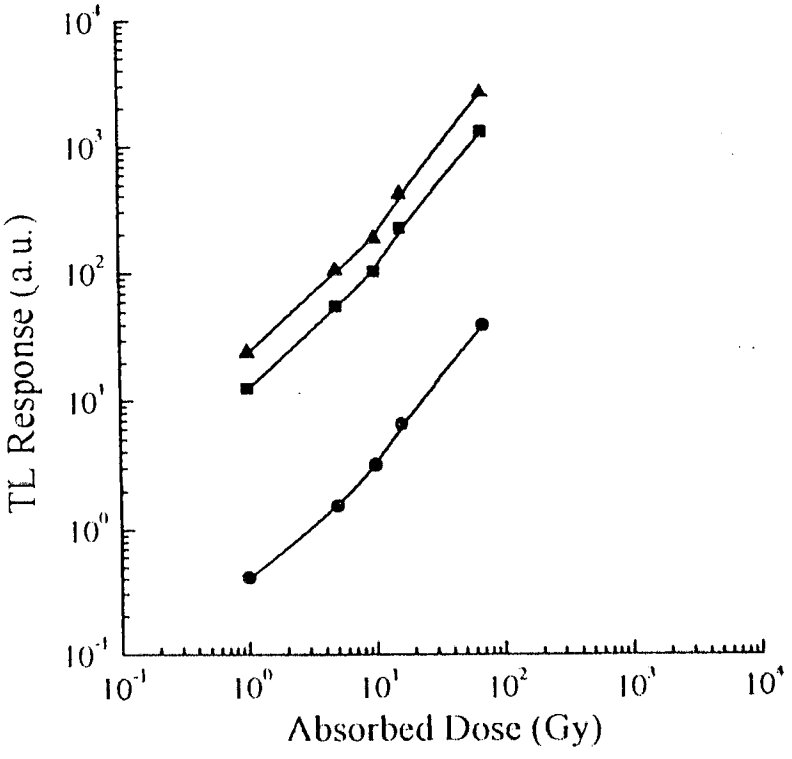
FIGURE CAPTIONS

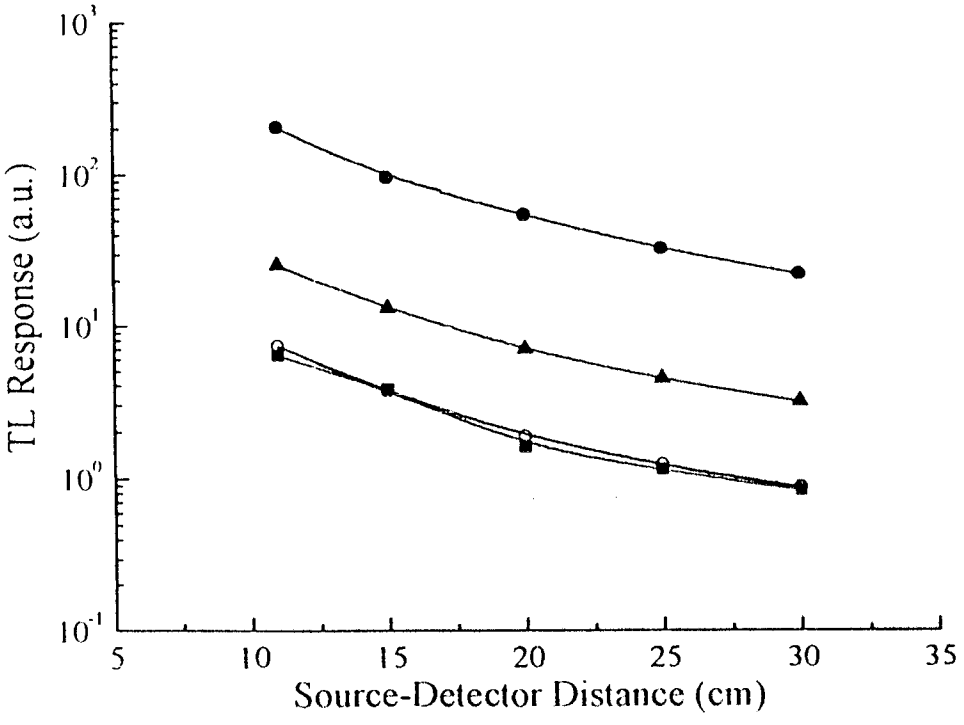
Figure 1 – Calibration curves for the $^{90}Sr+^{90}Y$ standard source, at 11 cm, for (a) TLD-100 (■), TLD-200 (●), TLD-400 (▲) and thin TLD-400 (○); measurement uncertainties were equal to 5.8%, 9.0%, 5.8% and 7.3%, respectively; and (b) thin $CaSO_4$:Dy (■), $CaSO_4$:Dy + 10%C (●) and $CaSO_4$:Dy (▲); measurement uncertainties were equal to 10.0%, 5.7% and 12.0%, respectively.

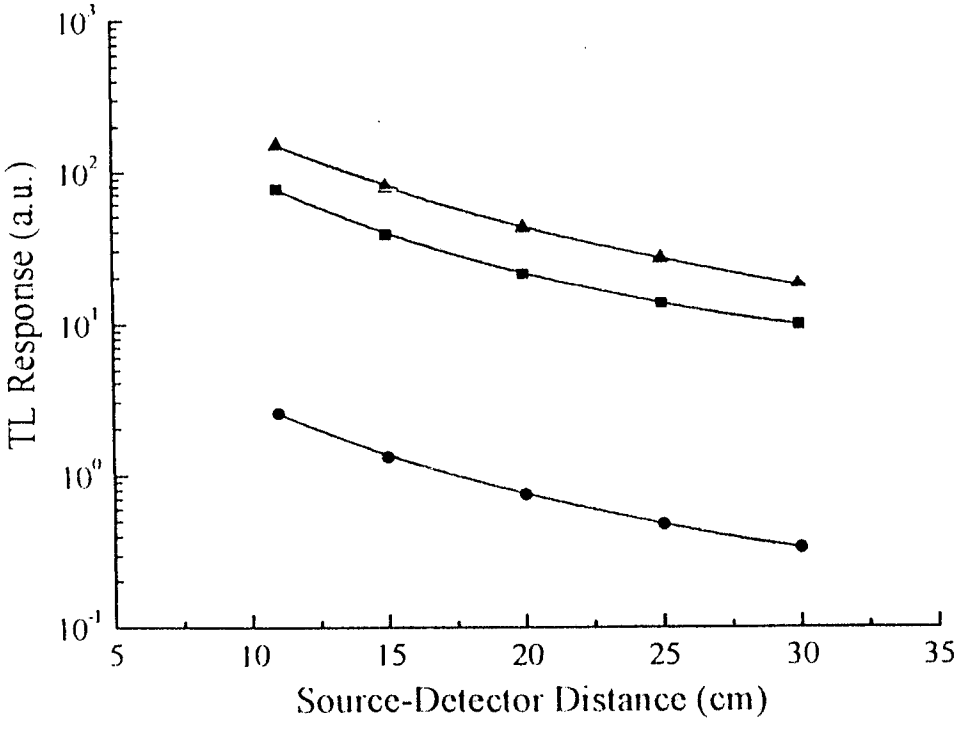
Figure 2 – TL response as a function of the source-detector distance ($^{90}Sr+^{90}Y$ standard source) for (a) TLD-100 (■), TLD-200 (●), TLD-400 (▲) and thin TLD-400 (○); measurement uncertainties were equal to 4.6%, 4.8%, 8.1% and 9.3%, respectively; and (b) thin $CaSO_4$:Dy (■), $CaSO_4$:Dy + 10%C (●) and $CaSO_4$:Dy (▲); measurement uncertainties were equal to 7.6%, 3.3% and 12.1%, respectively.

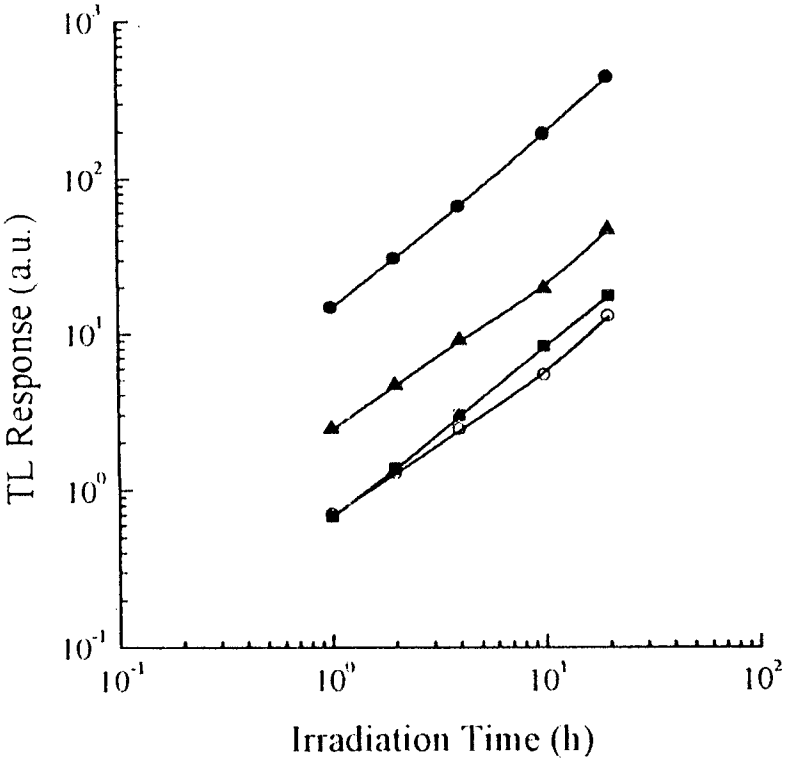
Figure 3 – Linearity of TL response for the $^{90}Sr+^{90}Y$ plane applicator, at 11 cm, for (a) TLD-100 (■), TLD-200 (●), TLD-400 (▲) and thin TLD-400 (○); measurement uncertainties were equal to 4.6%, 3.0%, 6.6% and 3.5%, respectively; and (b) thin $CaSO_4$:Dy (■), $CaSO_4$:Dy + 10%C (●) and $CaSO_4$:Dy (▲); measurement uncertainties were equal to 6.6%, 2.3% and 9.8%, respectively.

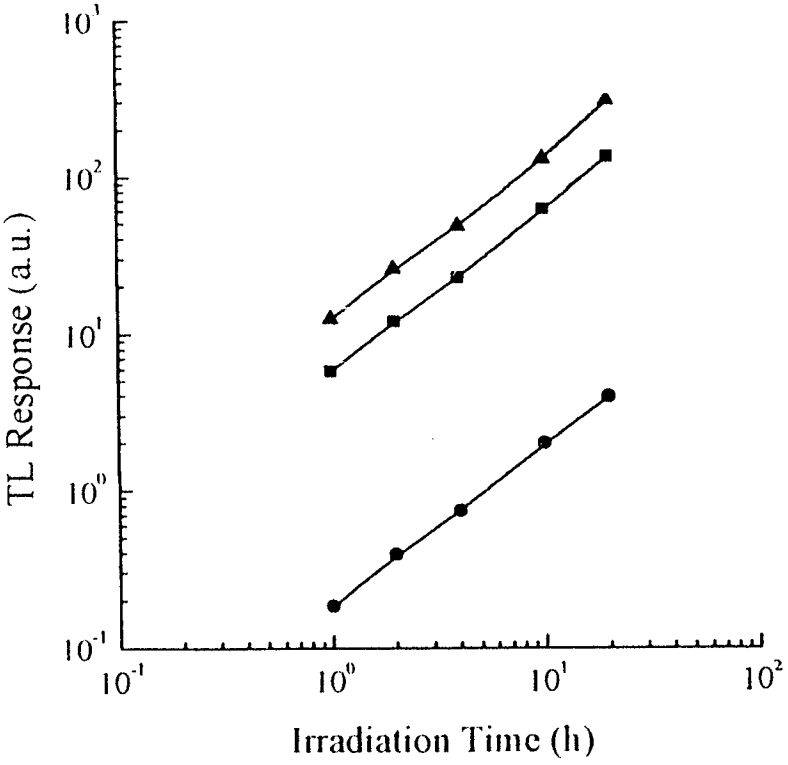

TL Response (a.u.)
Absorbed Dose (Gy)
10^-1
10^0
10^1
10^2
10^3
10^4


TL Response (a.u.)
Absorbed Dose (Gy)
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}


TL Response (a.u.)
10^3
10^2
10^1
10^0
10^{-1}
5
10
15
20
25
30
35
Source-Detector Distance (cm)


TL Response (a.u.)
10^3
10^2
10^1
10^0
10^{-1}
5
10
15
20
25
30
35
Source-Detector Distance (cm)


TL Response (a.u.)
10^3
10^2
10^1
10^0
10^{-1}
10^{-1}
10^0
10^1
10^2
Irradiation Time (h)


TL Response (a.u.)
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-1}
10^{0}
10^{1}
10^{2}
Irradiation Time (h)