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**DOSIMETRIC CHARACTERISTICS AND RADIATION MONITORING  
WITH  $\text{CaSO}_4(\text{Dy})\text{:NaCl}$  PELLETS**

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**CENTRO DE PROTEÇÃO RADIOLÓGICA E DOSIMETRIA  
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# DOSIMETRIC CHARACTERISTICS AND RADIATION MONITORING WITH $\text{CaSO}_4(\text{Dy})\text{:NaCl}$ PELLETS

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## ABSTRACT

$\text{CaSO}_4(\text{Dy})\text{:NaCl}$  TL dosimeters, in the form of pellets, are used in the field for a period of one month. Before using these pellets for environmental and personnel radiation monitoring, some of the important dosimetric characteristics like fading, reusability and effect of ambient light are investigated and described in this report. The pellets are used with plastic and lead filters for personnel and environmental radiation monitoring and the results obtained with the lead filters are in good agreement with those of the energy independent LiF dosimeters. A new combination of plastic, aluminium and lead filters is suggested for dose measurements in a mixed field of X, gamma and beta radiations.

## 1 – INTRODUCTION

Thermoluminescent (TL) dosimeters are being used routinely for dose measurements in many countries<sup>(4,6,7,8)</sup> because of their well known advantages over the film badges. Dosimetric characteristics of the TL phosphor  $\text{CaSO}_4\text{:Dy}$  in powder form have been investigated in detail by many workers<sup>(1,5)</sup>. The dosimetric peak appears at about 200°C and its intensity increases proportionally to the dose up to 10<sup>5</sup> rad.

TL response of  $\text{CaSO}_4(\text{Dy})\text{:NaCl}$  pellets is linear in the dose range of interest and is made energy independent by using the energy compensating filter: 0.8 mm thick lead disc with a central hole of diameter 2 mm<sup>(2)</sup>.

For radiation monitoring, pellets are placed in available plastic cassettes, originally designed for films used in personnel monitoring. They are placed at a few locations around the Instituto de Pesquisas Energéticas e Nucleares and also distributed to a selected number of personnel.

Results obtained with the  $\text{CaSO}_4(\text{Dy})\text{:NaCl}$  pellets are compared with those obtained with Harshaw LiF TLD-700 chips.

Finally, beta dose measurements carried out in the laboratory are described.

## 2 – EXPERIMENTAL

The TL phosphor  $\text{CaSO}_4(\text{Dy})$  is prepared by the well known evaporation method<sup>(9)</sup>. Cylindrical pellets of 6 mm in diameter and 1 mm thick are made using NaCl powder as a binder. The procedure for making the pellets will be reported soon<sup>(3)</sup>. The pellets were treated by a standard thermal annealing procedure of 400°C for 1 hour before use and the glow curves after irradiation were recorded by heating the pellets at the rate of 10°C/s in a Harshaw TLD reader. For studying the dosimetric characteristics of the pellets, glow curves were recorded in the TLD reader Model 2000 AB and, for

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routine radiation monitoring, Model 3000 was used. Temperatures  $T_1$  and  $T_2$ , between which integration of light is carried out, were chosen such that at temperature  $T_1$  the dosimetric peak starts rising and by the time  $T_2$  is attained the peak is completely recorded (Figure 1).

The film cassette consists of two plastic plates of dimensions  $3.8 \times 6.0 \times 0.5 \text{ cm}^3$  hinged together at the top along with a clip for wearing. As shown in Figure 2, the thicker plate has a 1.5 mm deep rectangular depression of dimensions  $3.0 \times 4.5 \text{ cm}^2$ , a through hole of diameter 1 cm at the location 1 (open window) and circular depressions of diameter 1.2 cm at the locations 2, 3 and 4 for inserting the filters. Plastic thicknesses at the locations 2, 3 and 4 are 2.3 mm, 2.5 mm and 2.9 mm, respectively. The plastic plate 3 mm thick has circular depressions of diameter 1.2 cm at the locations 2', 3' and 4' corresponding to the locations 2, 3 and 4. At these locations, plastic thicknesses are 1.8 mm, 2.0 mm and 2.2 mm, respectively. Lead filters of diameter 1.2 cm and thickness of 1 mm are fixed with silicon glue at the locations 3 and 3' and, lead filters of 0.8 mm thick with a central hole of diameter 2 mm are fixed at the locations 4 and 4'. When the cassette is closed, pairs of filters face each other. For radiation monitoring, three pellets sealed between two thin plastic foils were placed between these pairs of filters. No pellet was placed at the open window (location 1) due to interference from scattered radiation<sup>(9)</sup>.

### 3 – RESULTS AND DISCUSSIONS

#### 3.1 – Effect of Ambient Light

During the processes of thermal annealing, sealing with plastic foils and read-out, the pellets are exposed to ambient light. The following test was carried out to check if the dose measurements are affected by this light exposure.

Forty pellets, after standard thermal annealing treatment, were sealed with thin transparent plastic foils under low ambient light condition. Twenty of them were further covered with aluminium foil to protect from light. All the pellets were left together under normal ambient light.

The TL measurements of 20 pellets (10 from each batch) were carried out after one week of exposure to ambient light and for the remaining 20 pellets, after one month of exposure. Equivalent gamma doses were evaluated by comparing the results to the TL output due to a known dose of 100 mrad. It may be noted that, on the average, the two batches of pellets give nearly the same results after one week, namely, 3.9 mrad and 4.1 mrad for pellets not wrapped and wrapped in aluminium foil, respectively. After one month, the results were 13.9 mrad and 15.6 mrad, respectively. These values are higher than those after one week, due to the background of  $\sim 0.5 \text{ mrad/day}$ .

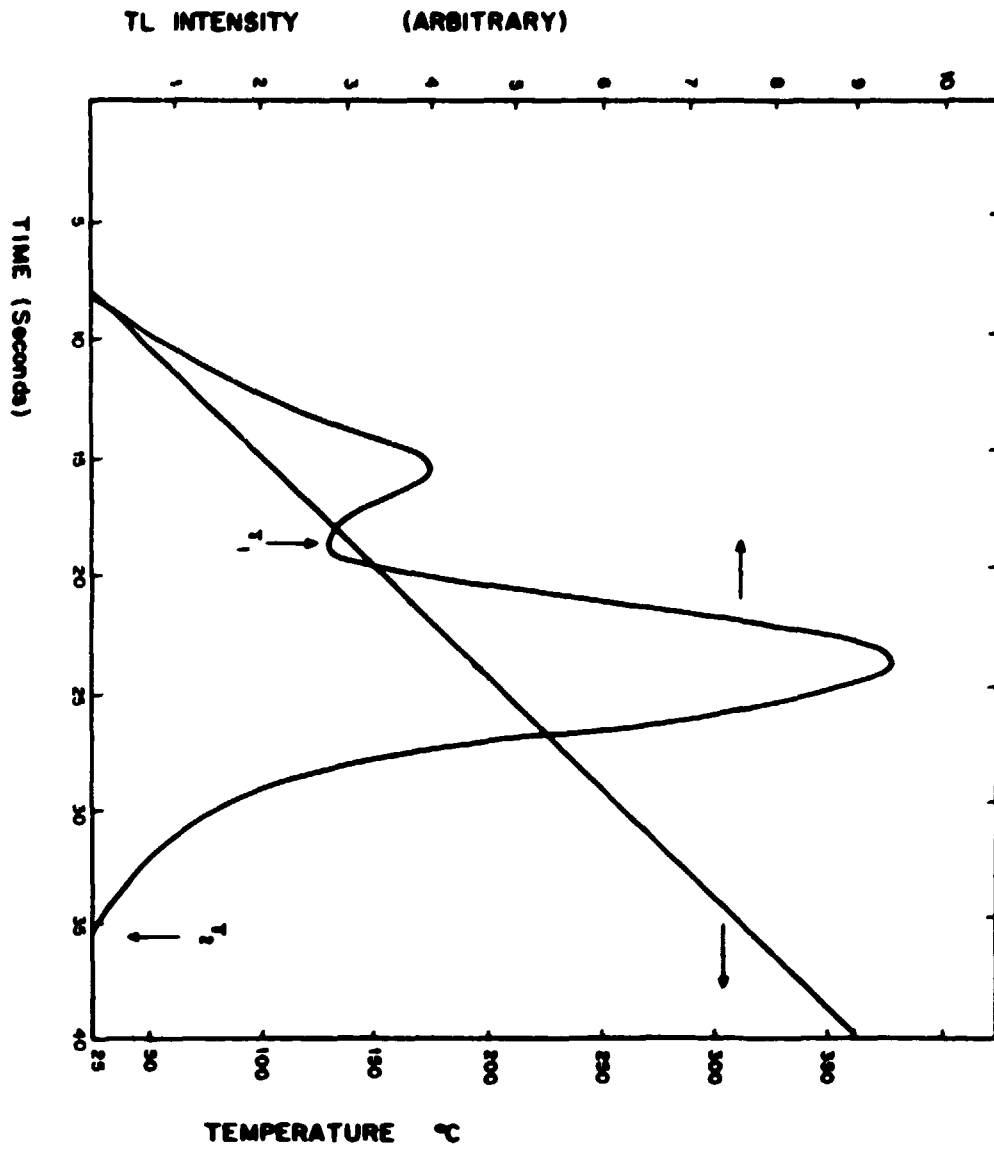
There is no significant build up or bleaching of TL due to continuous exposure to ambient light up to one month.

#### 3.2 – Fading of TL Response

The limiting factor for the long term use of TL dosimeters is fading, particularly in warm and humid countries. Fading characteristics of  $\text{CaSO}_4(\text{Dy})/\text{NaCl}$  pellets were investigated in the following way.

Ten pellets, after standard thermal annealing, were wrapped in an aluminium foil and given a gamma dose of 200 mrad under electronic equilibrium condition. These pellets were left in the environment along with 5 other pellets which had the same thermal treatment but did not receive any radiation dose. TL measurements were carried out, immediately after irradiation and after storing the pellets for varying times from 1 day to 1 month. For long storage periods, 10 days or more, there is

Figure 1 - Typical glow curve of TL pellet.



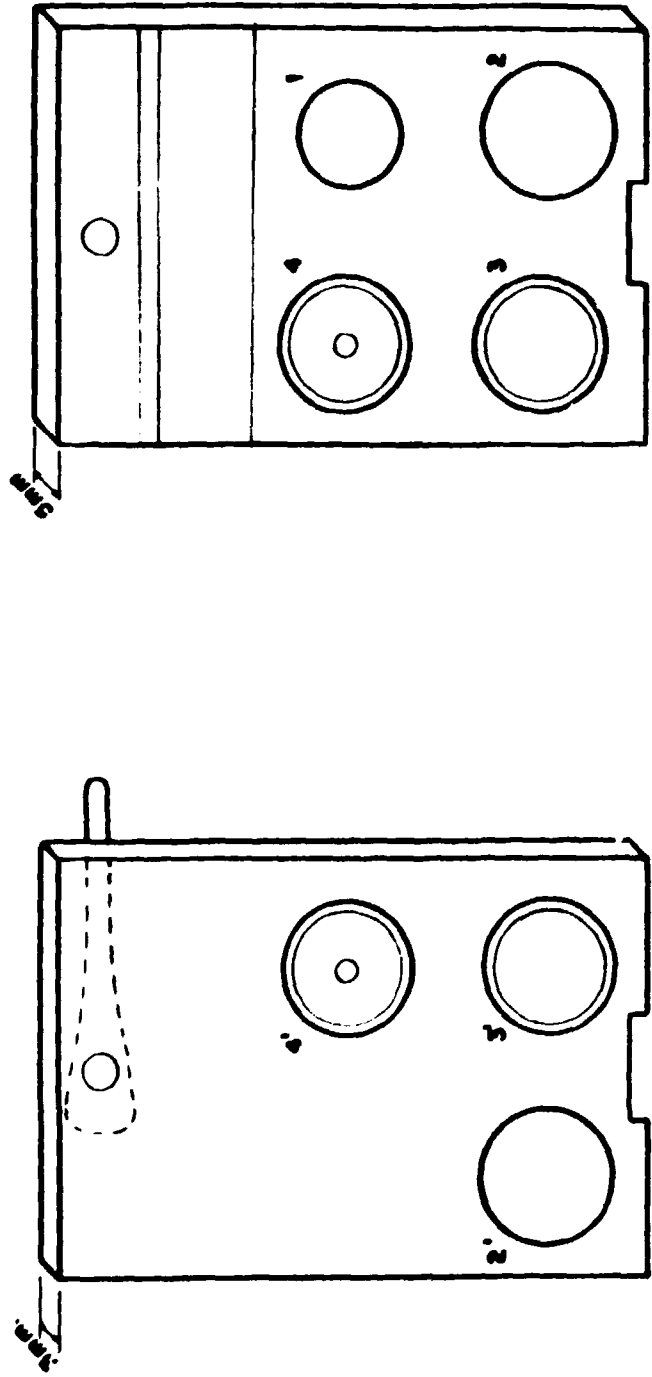


Figure 2 - Plastic badge with filters. 1) Open window; 2,2') Plastic; 3,3') Lead; 4,4') Lead with a central hole.

significant accumulation of TL in the pellets due to background radiation, which was estimated from the TL response of the unirradiated pellets and corrected for in the final analysis. Results are plotted in Figure 3, where each point is an average TL response of 10 pellets.

Normally, TL dosimeters are used for measuring the environmental and personnel doses, integrated over a period of one month. During this period, there is a fading of less than 7% in the TL response.

### 3.3 – Reusability

One of the advantages of the TL dosimeters over the film dosimeter is its reusability. LiF TLD-100 dosimeters have been reported to be reusable up to 50 times with an average decrease of sensitivity of 1% to 5%, depending upon the irradiation history<sup>(10)</sup>. For each reuse, TL dosimeters must be annealed at 400°C for 1 hour. Therefore, it is necessary to investigate the effect of repeated heating cycles on the TL sensitivity of  $\text{CaSO}_4(\text{Dy})\cdot\text{NaCl}$  pellets.

Twenty pellets were selected, presenting approximately the same TL sensitivity. They received a gamma dose of 100 mrad, under electronic equilibrium condition, after a standard thermal annealing, and their glow curves were recorded in the Harshaw 2000 AB TLD reader. After read-out, pellets were annealed and again given the same dose of 100 mrad under similar conditions and their glow curves were recorded. This process was repeated 10 times and the average TL response for each of the 20 pellets was determined.

None of the pellets shows a standard error of more than  $\pm 3\%$  by repeated irradiation and heating cycles at least up to 10 times. By taking the average TL response of 20 pellets, the standard error found in 10 times of repeated use is  $\pm 1.3\%$ . Therefore,  $\text{CaSO}_4(\text{Dy})\cdot\text{NaCl}$  pellets can be used repeatedly without recalibration. However, care must be taken that the instrument sensitivity remains always the same over the period of measurements.

### 3.4 – Environmental and Personnel Radiation Monitoring

After ascertaining the suitability of  $\text{CaSO}_4(\text{Dy})\cdot\text{NaCl}$  pellets in dose measurements it was decided to use them in the field for environmental and personnel radiation monitoring. A large number of pellets were used for this purpose, which presented a wide variation in their TL sensitivity. Therefore, to estimate an unknown dose, it is necessary to determine a calibration factor for each pellet. This factor is obtained by dividing the TL response to a known dose by this given dose.

The procedure adopted for distribution of cassettes, reading of pellets and evaluation of doses is the following:

Fifty individuals were selected for radiation monitoring using  $\text{CaSO}_4(\text{Dy})\cdot\text{NaCl}$  pellets. Simultaneously, LiF TL dosimeters were also distributed for comparison of the results.

Just before dispatching to the field, the pellets are thermally annealed, sealed in batches of three and placed in plastic cassettes. Two of such cassettes are retained in the laboratory as control dosimeters and two more were stored in a lead box of 10 cm wall thickness and with a top cover of 8 cm thick. After one month of use in the field, the dosimeters are sent back to the laboratory. Immediately after their arrival, they are stored along with the control dosimeters in the lead box until the TL readings are taken. A record of all the relevant data, e.g., date of standard thermal annealing, date of dispatch, period of use, date of receipt and date of TL reading, is maintained.

After carrying out the TL measurements, pellets were annealed and exposed to a gamma dose of 100 mrad, under electronic equilibrium condition, between lucite plates of thickness 3 mm each. The

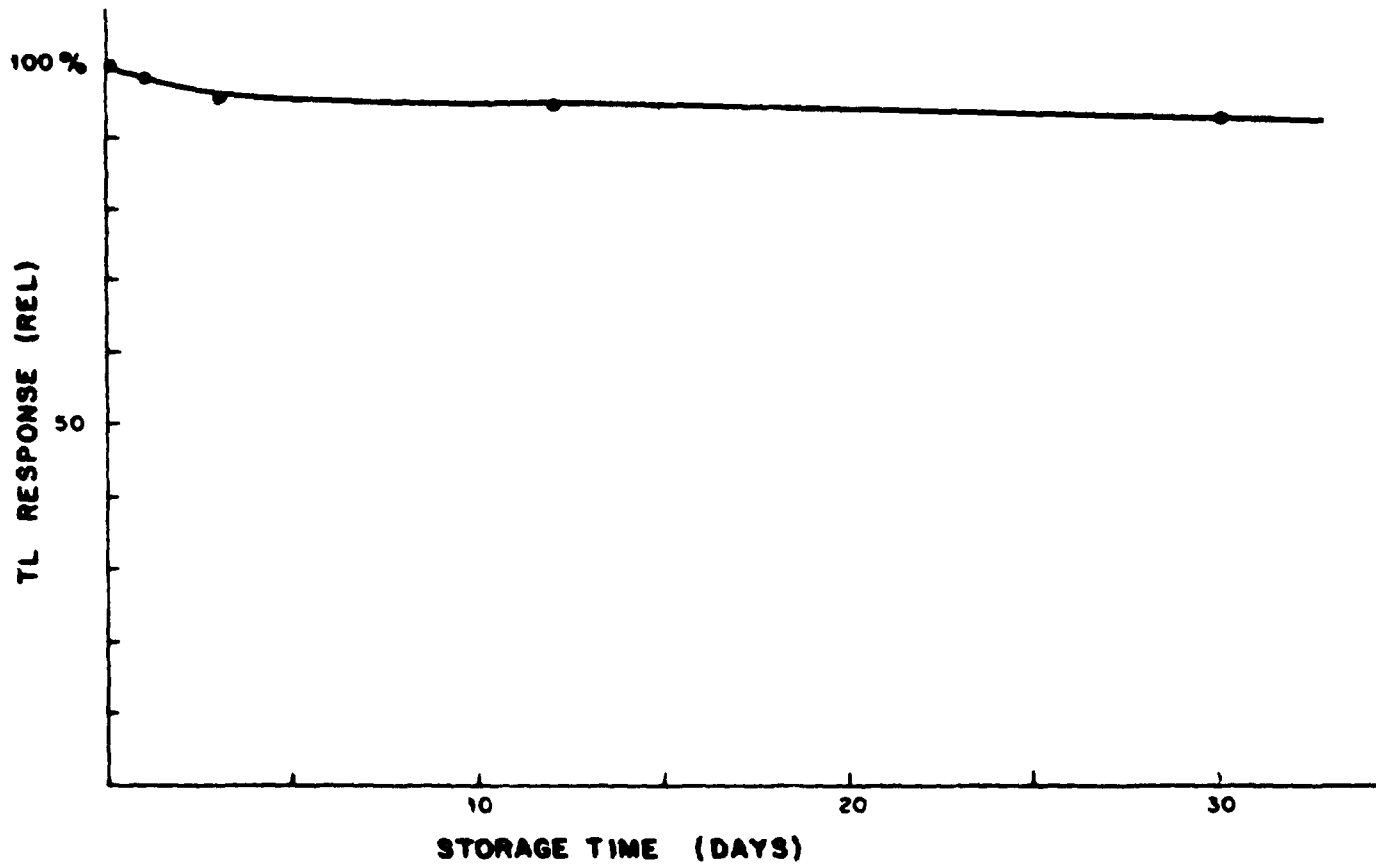


Figure 3 - Fading of response with time by storing at room temperature.

calibration factor was determined for each pellet and the unknown dose estimated from the ratio between the TL light output and the calibration factor.

In order to estimate the attenuation caused by the filters, 30 annealed pellets were first calibrated by giving 6 known doses to each pellet, between the lucite plates, successively from 5 mrad to 500 mrad. Calibration factors ( $X_1$ ) were determined from the slopes of straight line of TL response versus dose. These pellets were then placed in 10 plastic cassettes (3 pellets in each cassette) and again calibrated by giving a few known doses. Calibration factors  $X_2$ ,  $X_3$  and  $X_4$  for the pellets irradiated between the plastic filters and the two lead filters (without and with a central hole) were determined from the slopes of the straight line TL response of the respective pellets. Typical graphs for three pellets, irradiated between lucite plates and in plastic cassettes are shown in Figure 4. Attenuation by the three filters in the plastic cassette is estimated by taking the ratios  $X_1/X_2$ ,  $X_1/X_3$  and  $X_1/X_4$  and it is found that plastic filter does not produce any attenuation and an average attenuation of 7% and 5% is produced by lead filters without and with a central hole, respectively. Dose values estimated before are corrected for by these fractions. Finally, with the help of the control dosimeters, a correction is made for the dose received by the pellets during storage in the laboratory.

### 3.4.1 – Results

Tests using  $\text{CaSO}_4(\text{Dy})\text{:NaCl}$  pellets in personnel and environmental radiation monitoring started in our Institute in August 79 and November 79, respectively. These tests were performed routinely for a period of 10 months. LiF dosimeters were placed in another plastic cassette at the open window location and between lead filters.

In personnel radiation monitoring nearly the same dose is recorded by the pellets placed between lead filters with hole as well as without hole, in each plastic cassette, indicating the absence of soft gamma or X-radiations in the field.

Results obtained with  $\text{CaSO}_4(\text{Dy})\text{:NaCl}$  pellets and LiF dosimeters, both between lead filters indicate that the TL response of 68% of the cases is in agreement within  $\pm 10\%$ . In a smaller percentage of the cases, the values obtained with  $\text{CaSO}_4(\text{Dy})\text{:NaCl}$  pellets in plastic filter and LiF dosimeters at the open window locations are higher than those in lead filters and also differ widely between both samples. This is because in the personnel use such badges are also exposed to beta radiation in addition to the gamma radiation, the beta radiation being stopped partially by the plastic filters. Therefore, dose values obtained for  $\text{CaSO}_4(\text{Dy})\text{:NaCl}$  pellets are lower than those for LiF dosimeters. Beta dose measurements carried out using the  $\text{CaSO}_4(\text{Dy})\text{:NaCl}$  pellets in the present plastic cassette are described in the following section.

Nearly the same dose is recorded for all the three pellets of the environmental cassettes indicating the absence of beta radiations in the environment. It was noted that the control dosimeter, which was stored near the wall of a room, shows the highest dose. This is possibly because of radioactivity present in the concrete wall.

### 3.5 – Beta Radiation Dosimetry

Four  $\text{CaSO}_4(\text{Dy})\text{:NaCl}$  pellets having same TL response were selected, thermally annealed and placed in a plastic cassette in the usual way. The plastic cassette was irradiated with a 20 mCi  $\text{Sr-90}$  beta source at a distance of 15 cm for 1 min with open window facing the source. After read-out, pellets were annealed and the same process was repeated two times more.

It is observed that a significant fraction, 57.6%, of beta radiation is cut off by the 2.3 mm thick plastic filter. Lead filter stops beta radiation nearly completely as well as gamma radiation below

- IRRADIATION BETWEEN LUCITE PLATES
- ▲ IRRADIATION IN PLASTIC CASSETTE

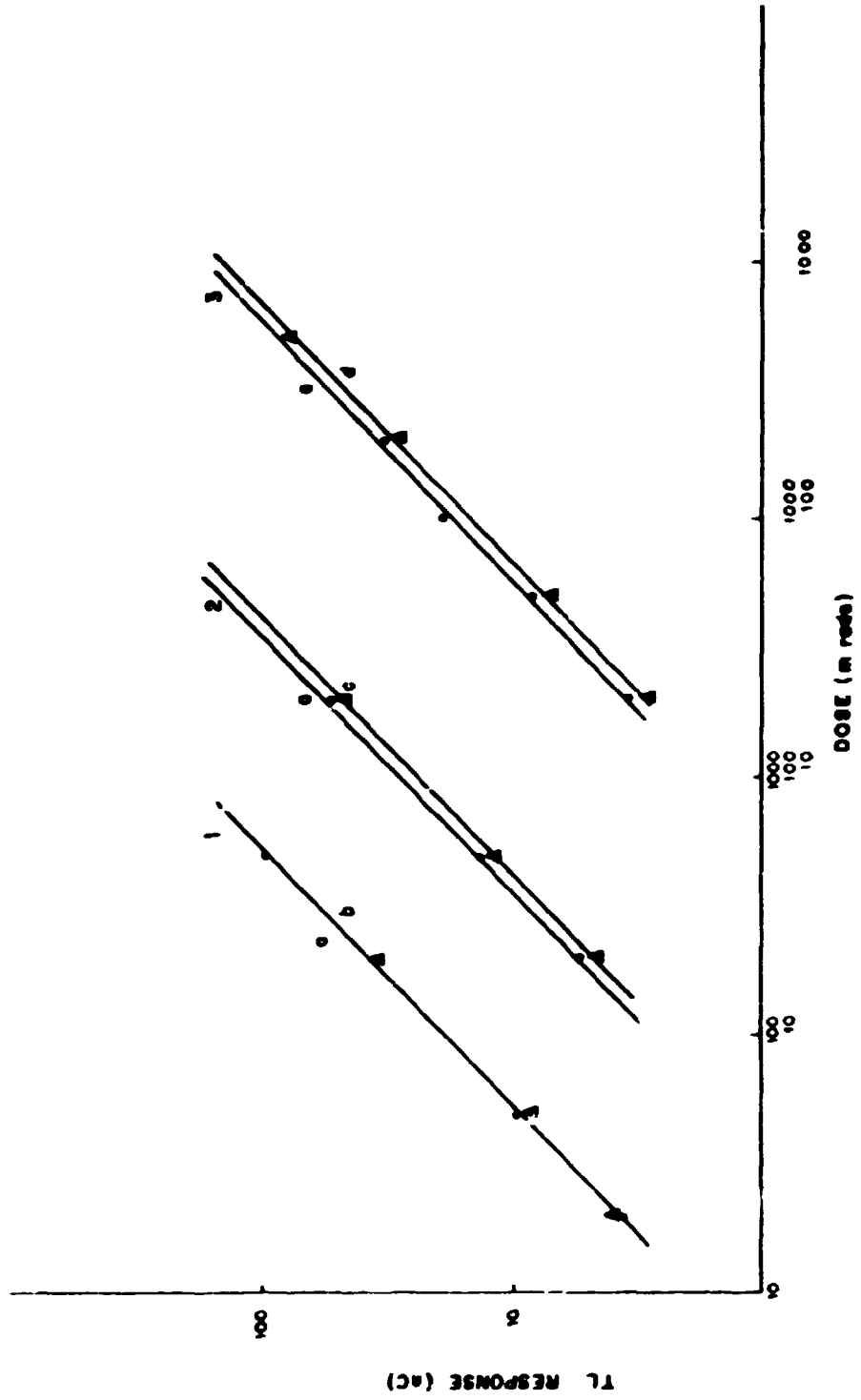


Figure 4 -- Typical TL response for 3 pellets irradiated between lucite plates (a) and the filters: plastic (b), lead (c) and lead with a central hole (d).

100 keV<sup>(2)</sup>. Therefore, a difference between the two readings will not give an estimate of beta radiation in a mixed field of X, gamma and beta radiation.

In order to achieve a better discrimination between different radiations the thickness of the plastic filter was reduced to 1 mm and the lead filter was replaced by an aluminium filter of thickness 1.5 mm which transmits X and gamma radiations above 40 keV.

The behaviour of the new cassette exposed to Sr-90 beta radiation was tested in the following way: Twelve annealed CaSO<sub>4</sub>:Dy<sup>3+</sup>:NaCl pellets were irradiated with a Sr-90 beta source at 15 cm for 1 min in 3 batches and their glow curves were recorded. After standard thermal annealing, these pellets were given the same beta dose by irradiating 4 pellets at a time in the plastic cassette and their glow curves were again recorded. From the ratio of the two sets of readings, the percentage transmitted through the filters is determined and given in Table I.

**Table I**  
TL Response to Beta Radiations in the Modified Cassette

Filters	Unfiltered TL response (nC)	Filtered TL response (nC)	% Response relative to unfiltered response	% Response (average)
Open window	41.65	37.70	90.5	
Open window	38.60	42.50	110.1	101.9
Open window	32.25	33.90	105.2	
1 mm plastic	32.35	27.65	85.5	
1 mm plastic	34.00	29.40	86.5	85.0
1 mm plastic	30.55	25.40	83.1	
2.5 mm plastic	33.30	1.481	4.4	
+ 1.5 mm Al	25.25	0.905	3.6	3.7
+ 1.5 mm Al	39.80	1.237	3.1	
2.9 mm plast. +	40.20	1.129	2.8	
0.8 mm lead	30.05	1.090	3.6	3.2
with a hole	30.65	0.989	3.2	

On the average 85% of the beta radiation is transmitted through the 1 mm thick plastic filter while 2.5 mm thick plastic filter + 1.5 mm thick aluminium filter stops 96.3% of the radiation.

Difference of the two readings after correcting for the attenuation (15%) caused by the plastic filter, will give the beta dose within 5% error. TL response to gamma radiation using 1 mm thick plastic filter will be less than using 3 mm thick plastic filter, because of incomplete electronic build up. But no additional error will be committed, if the calibration is done under similar conditions. Therefore, for measurement of dose in a mixed field of X, gamma and beta radiations, three pellets with the following filters may be used:

- i) 1 mm thick plastic filter for measurement of X, gamma and beta radiations together.
- ii) 1.5 mm thick aluminium filter which will stop nearly all the beta radiation and allow measurement of X and gamma radiations.
- iii) 0.8 mm thick lead with a central hole of diameter 2 mm which makes the response of the pellet energy independent for electromagnetic radiations, allowing correct dose estimation due to the mixed field of gamma and low energy X radiations.

## SUMMARY

The results obtained in this work show that there is no significant build up or bleaching of TL response of the  $\text{CaSO}_4(\text{Dy})\cdot\text{NaCl}$  pellets due to continuous exposure to ambient light up to one month. During this period, there is a fading of less than 7% in the TL response. Repeated annealing and read-out cycles do not have significant effect on the sensitivity of the pellets.

Tests using  $\text{CaSO}_4(\text{Dy})\cdot\text{NaCl}$  pellets with a combination of plastic, lead and lead with hole filters, in personnel and environmental radiation monitoring during 10 months, simultaneously with energy independent LiF dosimeters, showed that gamma dose values obtained with the two systems are in good agreement. A new combination of plastic, aluminium and lead filters is suggested for dose measurements in a mixed field of X, gamma and beta radiations.

This result shows that the  $\text{CaSO}_4(\text{Dy})\cdot\text{NaCl}$  pellet dosimeter can be used satisfactorily for personnel and environmental radiation monitoring.

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## RESUMO

Dosímetros TL foram utilizados durante o período de um mês, para a monitoração de radiação. Verificou-se que não há efeito da luz ambiente normal na resposta TL dos dosímetros de  $\text{CaSO}_4(\text{Dy})\cdot\text{NaCl}$  durante esse período. O sinal TL apresenta decaimento na temperatura ambiente de cerca de 7%. O erro padrão médio encontrado após dez vezes de uso repetido dos dosímetros foi de  $\pm 1,3\%$ .

Os dosímetros são utilizados com filtros de plástico e chumbo para a dosimetria pessoal e ambiental. Os resultados obtidos com filtros de chumbo concordam com os obtidos com os dosímetros de LiF, independentes com a energia. Uma nova combinação de filtros de plástico, alumínio e chumbo é sugerida para a medida de dose em campos mistos de radiação X, beta e gama.

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