International Conference on Solid State Dosimetry SSD-
New Haven, EUA, 27/6 a 2/7 2004.

Dosimetric characterization of thermoluminescent materials for beta monitoring at nuclear medicine services

Sonia G. P. Cecatti[1,2] and Linda V. E. Caldas[2]

[1] FUNDACENTRO, Ministério do Trabalho e Emprego, São Paulo, SP, Brazil.

P. O. Box 11484, 05422-970, São Paulo, SP, Brazil.

[2] Instituto de Pesquisas Energéticas e Nucleares, Comissão Nacional de Energia Nuclear.

P. O. Box 11049, 05422-970, São Paulo, SP, Brazil.

e-mail: scecatti@fundacentro.gov.br

e-mail: lcaldas@ipen.br

81

11038

Dosimetric characterization of thermoluminescent materials for beta monitoring at nuclear medicine services

Sonia G. P. Cecatii[1, 2] and Linda V. E. Caldas[2]

Abstract

Beta emitters are widely used in nuclear medicine for diagnostic and therapeutic purposes. The critical groups exposed to a radioactive patient include the staff, other patients and members of the public accompanying the patient. The aim of this work is to characterize thermoluminescent materials for the staff monitoring of nuclear medicine services that manipulate beta radiation solutions of ^{153}Sm. This study was performed using $CaSO_4$:Dy + Teflon pellets, produced at IPEN, with different dimensions. For the dosimetric characterization, these thermoluminescent dosemeters were exposed to gamma source (^{60}Co) and to beta sealed sources ($^{90}Sr+^{90}Y$, ^{204}Tl and ^{147}Pm) and to a non-sealed source (^{153}Sm). Results were obtained related to reproducibility, lower detection limits, calibration curves, energy and angular dependence. All tested materials show usefulness for monitoring of workers exposed to beta radiation.

INTRODUCTION

There is no doubt that beta irradiation of workers occurs in practice. Evidence is given by the services which, on the basis of measurements with the available personal dosemeters, were able to identify facilities with significant beta radiation exposures, i.e. in particular in nuclear medicine, industry and research [1].

Beta emitters are widely used in nuclear medicine for diagnostic and therapeutic purposes. Contradictory to most of the gamma emitters, the energy of beta radiation can be totally absorbed in a small tissue volume. Critical groups exposed to a radioactive patient include the staff, other patients and members of the public accompanying the patient. Nuclear medicine staff members typically receive a radiation exposure to the whole body and hands resulting from the dose preparation and injection of the radiopharmaceuticals and blood pressure monitoring tasks of quantitative studies. Hands receive a much higher radiation dose than other parts of the body[2].

Extremity dose assessments are usually carried out using thermoluminescent (TL) detectors because of their convenient size. For accurate measurement of Hp (0.07) the dosemeter must be thin to avoid significant attenuation of the radiation[3]. Therefore, the response of most thermoluminescent dosemeters to beta radiation depends on both the radionuclide and the irradiation geometry. The dosemeter also needs to be robust, because it may be placed on the hands carrying out manual work.

Nuclear medicine technologists receive small amounts if radiation each workday[4]. They work almost exclusively in the energy range between 60 and 700 keV.

The main dosimetric characteristics of $CaSO_4$:Dy pellets produced at Instituto de Pesquisas Energéticas e Nucleares (IPEN) studied in this work were already reported by

Campos[5 - 7]. In order to monitor ^{153}Sm using a wrist dosemeter, these characteristics had to be determined again, to allow the elaboration of the calibration curves for ^{153}Sm.

Therefore, the objectives of this work were the dosimetric characterization of $CaSO_4$:Dy Teflon pellets for beta radiation detection using the thermoluminescent method, and a proposal of a TL dosemeter for workers exposed to beta radiation of ^{153}Sm. A prototype of a wrist dosemeter is presented.

MATERIALS AND METHODS

Three types of $CaSO_4$:Dy Teflon pellets, produced at the Laboratory of Dosimetric Materials of the IPEN, for radiation detection were utilized[5 – 7]. Table 1 presents the physical characteristics of the studied $CaSO_4$:Dy Teflon pellets. They were thermally treated at 300°C during one hour for re-utilisation.

The beta secondary standard system of the Calibration Laboratory at IPEN, with $^{90}Sr + ^{90}Y$, ^{204}Tl and ^{147}Pm sources, manufactured by Buchler GmbH & Co, Germany, with traceability to the primary standard laboratory Physikalisch - Technische Bundesanstalt (PTB), Germany, was utilized for the beta irradiations. The detectors were always placed on a 15 mm thick phantom of polymethylmethacrylate (Lucite) and covered with a plastic foil of 1.20 x $mg.cm^{-2}$ (area density) during the irradiations.

The gamma irradiations were carried out using a ^{60}Co source under electronic equilibrium conditions, that is, the samples were placed between 3 mm thick Lucite plates.

The beta irradiations were realized using a non-sealed reference source of ^{153}Sm (517.2 kBq), produced by the Center for Radiopharmacy, IPEN, with calibration in activity by the Nuclear Metrology Laboratory, IPEN. This source presents a very short half-life (46 h) and a mean energy of 290 keV. The TL pellets were irradiated positioned on the Lucite phantom and on a wrist dosemeter. The wrist dosemeter prototype is composed by a Minolta-type watch and four TL pellets. The watch core was substituted by a plastic plate of expanded polyvinylchloride (PVC) with 31 mm in diameter and 3 mm in thickness (Fig. 1). The detectors can easily be inserted or removed by pressing the plate into or out of the watch badge back. To cover and to maintain the detectors into the wrist badge, foils of black polystyrene (black plastic foils), with 64 $mg.cm^{-2}$ of area density were utilized. An advantage of the TL proposed wrist dosemeter prototype is that its material and design turn it comfortable for the users.

The TL measurements were obtained using a Harshaw Nuclear System, model 2000A/B, with a linear heating rate of $10°C.s^{-1}$. The reading cycle was performed within 26 s, with a constant flux of N_2 of 4.0 $l.min^{-1}$. Light emission was integrated in the temperature interval between 140°C and 240°C.

RESULTS AND DISCUSSION

Glow curves

The TL glow curves for the three kinds of $CaSO_4$:Dy Teflon dosemeters irradiated with 10 mGy ($^{90}Sr + {}^{90}Y$) present two peaks, one at 145°C and the other, more intense, at about 220°C (dosimetric peak).

Reproducibility

The reproducibility study of the TL response of the $CaSO_4$:Dy Teflon pellets was carried out for each dosemeter type by calculating the standard deviations from the successive TL measurements. The individual reproducibility obtained for the pellets irradiated with 2 mGy (^{60}Co) under identical conditions was 3.1% (1σ, k=1) for $CaSO_4$:Dy (50 mg), 2.6% for $CaSO_4$:Dy (20 mg) and 3.2% for $CaSO_4$:Dy + 10 % C, that are comparative values to those presented by Campos[6, 7]: 3.0 % and 2.2 % for $CaSO_4$:Dy (20 mg) and $CaSO_4$:Dy + 10 % C, respectively.

Lower detection limits

The lower detection limits were determined studying the variations of the signals obtained by the readings of non-irradiated detectors. They were determined as $D_{min} = [\overline{TL}(0R) + 3\sigma] \times F_c$, where $\overline{TL}(0R)$ is the mean value of 10 replicate zero-dose readings, of a set of twenty pellets; σ is the standard deviation from the mean value and F_c is the calibration factor of the detectors to beta radiation. The lower detection limits obtained for $CaSO_4$:Dy (50 mg), $CaSO_4$:Dy (20 mg) and $CaSO_4$:Dy + 10 % C were 14 μGy, 24 μGy and 58 μGy, respectively. These results are comparative to those obtained by Campos[5 – 7]: 10 μGy, 30 μGy and 23 μGy for the same types of pellets of $CaSO_4$:Dy, respectively.

Calibration curves

The TL response of the different types of $CaSO_4$:Dy Teflon dosemeters was obtained as a function of absorbed dose of beta radiation of the ^{90}Sr + ^{90}Y source.

Figure 2 shows linearity of the TL response between 1 Gy and 1 kGy, and the usefulness of all TL detectors in the whole tested interval. The measurement uncertainties were always within 5.0%. It can be observed that the TL detectors present different TL sensibility. Linearity of TL response of these materials was already reported by Campos [5 - 7].

Energy dependence

The TL response of the three types of $CaSO_4$:Dy Teflon dosemeters was measured for $^{90}Sr + ^{90}Y$, ^{240}Tl and ^{147}Pm beta sources, normalized to the response of the $^{90}Sr + ^{90}Y$ irradiation. Figure 3 shows the energy dependence of the $CaSO_4$:Dy detectors. The $CaSO_4$:Dy (50 mg) and the $CaSO_4$:Dy (20 mg) dosemeters present almost the same very high energy dependence, while the $CaSO_4$:Dy + 10 % C dosemeter present an energy dependence of 60% in the studied energy interval.

Angular dependence

The angular dependence of the TL response of the detectors was also investigated. The angular response for all detectors was measured at different angles (0°, 2°, 4°, 10°, 30°, 45°, 60° and 90°) in $^{90}Sr + ^{90}Y$ radiation beams. The TL pellets were irradiated with an absorbed dose of 3.5 mGy. Figure 4 presents the TL response as a function of the angle of incidence of the radiation. An accentuated angular dependence is observed only from 45° on.

Determination of absorbed doses of ^{153}Sm

All three types of $CaSO_4$:Dy Teflon detectors were exposed to the ^{153}Sm source, on the Lucite phantom and on the wrist dosemeter prototype. The distance between the source and the detectors was kept constant and equal to 1 cm. The absorbed doses had to be larger when the samples were irradiated in the wrist dosemeter due to technical conditions. The irradiations were realized with and without the black plastic foil covering the detectors. The attenuation factor of the black plastic foils was determined as 1.20.

As the ^{153}Sm source was not calibrated in terms of absorbed dose rates, but only in terms of activity, the calibration curves of the TL response for the $CaSO_4$:Dy Teflon pellets as a function of the absorbed dose were determined using the calibration curves for ^{90}Sr + ^{90}Y and the energy dependence curves obtained in this work. The results are shown in Figures 5 and 6, for measurements on the Lucite phantom and using the wrist dosemeter, respectively. Linearity of the TL response was obtained in all cases. Comparing the results of the Lucite phantom and the wrist dosemeter, an increase in the TL response was observed when the dosemeters were positioned on the wrist, that may indicate a possible occurrence of different back-scattering than in the Lucite phantom. This fact has to be taken into consideration for the dose determination, or the TL pellets shall be calibrated in the wrist dosemeter (as they were in this work).

CONCLUSIONS

The characteristics of the three types of $CaSO_4$:Dy Teflon pellets tested showed their usefulness for monitoring of workers exposed to beta radiation in nuclear medicine, using the Lucite phantom and the wrist dosemeter prototype for ^{153}Sm radiation.

ACKNOWLEDGEMENTS

The authors are thankful to Dr. M. F. Koskinas for the preparation and calibration of the ^{153}Sm standard source, to L. L. Campos for providing the $CaSO_4$:Dy pellets, and to Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Brazil, for partial financial support of this work.

REFERENCES

1. Regulla, D.F. Importance of exposure to beta particles in practical radiation protection. Radiat. Prot. Dosim. 14(2): 95-100 (1986).
2. Tsopelas, C.; Collins, P.J. and Blefari, C. A simple and effective technique to reduce staff exposure during the preparation of radiopharmaceuticals. J. Nucl. Med. Technol. 31: 37-40 (2003).
3. Berus, D.; Cobens, p.; Buls, N.; Van den Broeck, M.; Van Holsbeeck, G. and Vanhavere, F. Extremity doses of workers in nuclear medicine: mapping hand doses in function of manipulation. Proceedings of 11th International Congress of the International Radiation Protection Association. Madrid, Spain, May 2004.
4. Thompson, M.A. Maintaining a proper perspective of risk associated with radiation exposure. J. Nucl. Med. Technol. 29: 137-142 (2001).
5. Campos, L. L. and Lima, M. F. Dosimetric properties of $CaSo_4$:Dy teflon pellets produced at IPEN. Radiat. Prot. Dosim. 14(4): 333-335 (1986).
6. 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).*
7. Campos, L. L. Graphite mixed $CaSO_4$:Dy TL dosemeters for beta radiation dosimetry. Radiat. Prot. Dosim. 48(2): 205-207 (1993).

FIGURE CAPTIONS

Figure 1. Set-up for the detectors in the watch badge (wrist dosemeter).

Figure 2. Calibration curves of $CaSO_4$:Dy TL pellets to beta radiation (^{90}Sr+90Y), on the Lucite phantom.

Figure 3. Energy dependence of CaSO4:Dy pellets to beta radiation.

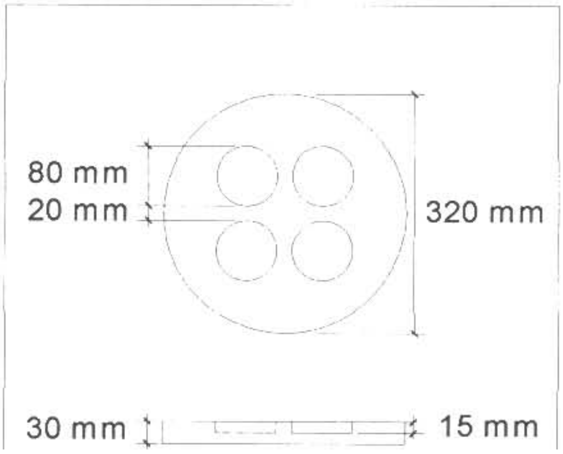
Figure 4. Angular dependence of $CaSO_4$:Dy pellets for ^{90}Sr + ^{90}Y (3.5mGy).

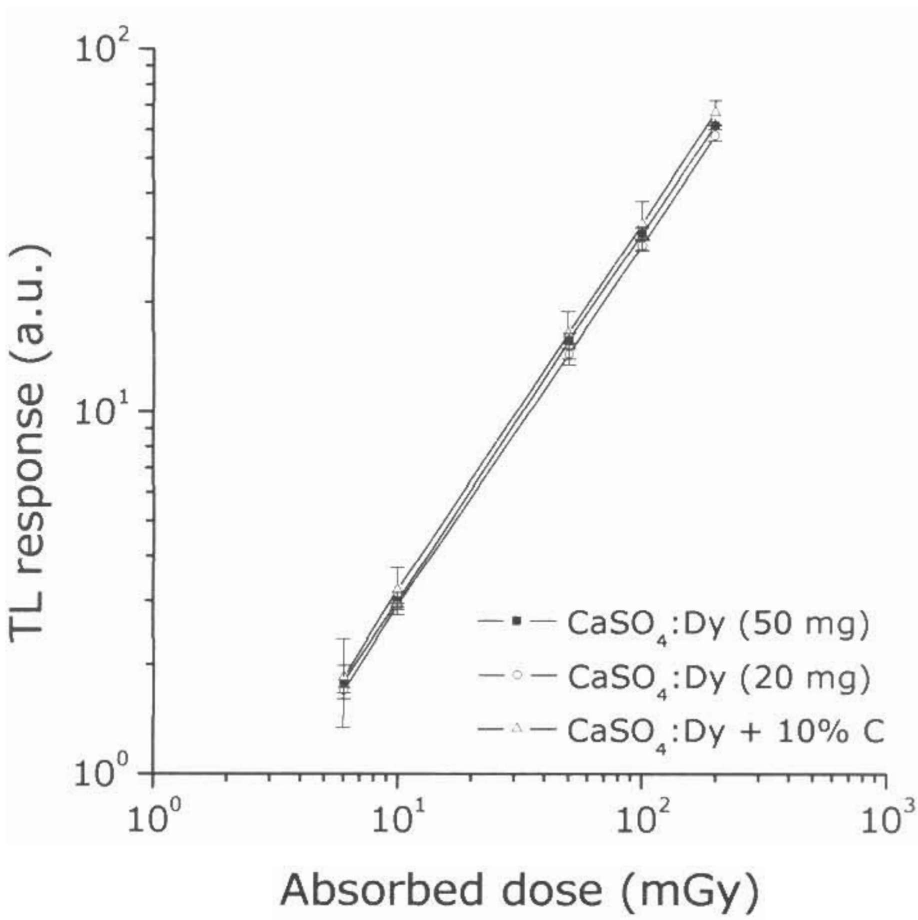
Figure 5. Calibration curves for $CaSO_4$:Dy pellets to beta radiation (^{153}Sm).

Figure 6. Calibration curves for $CaSO_4$:Dy pellets to beta radiation (^{153}Sm).

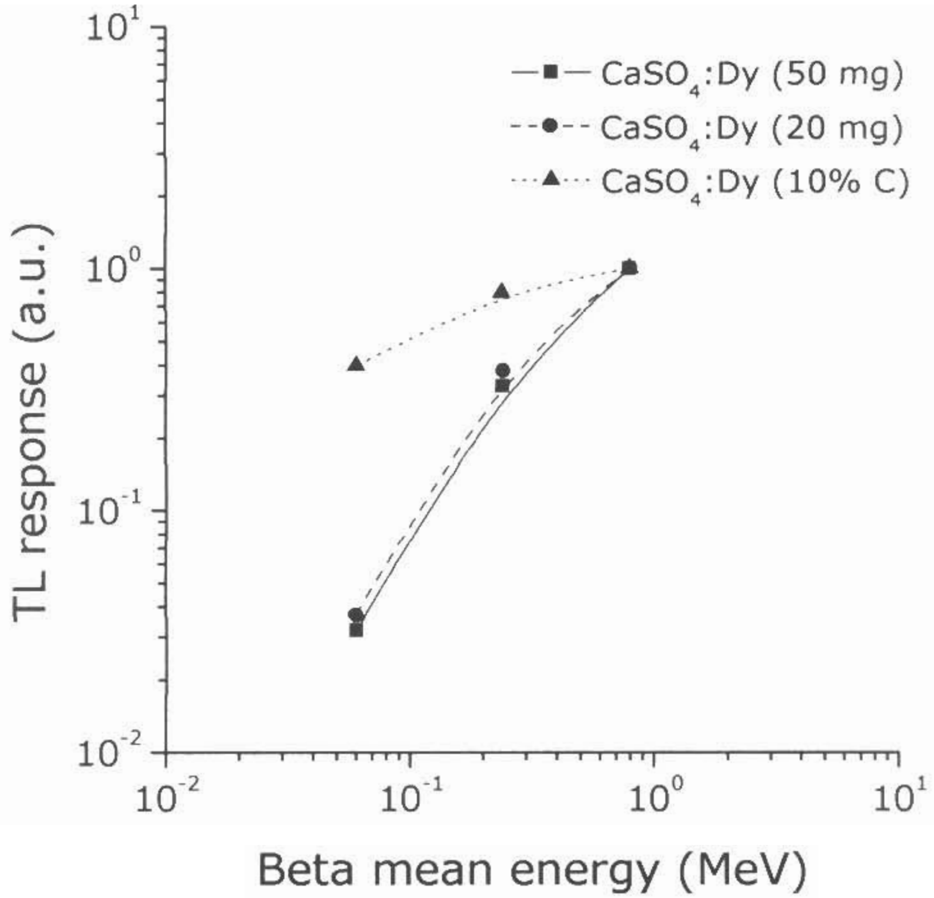
TABLE CAPTION

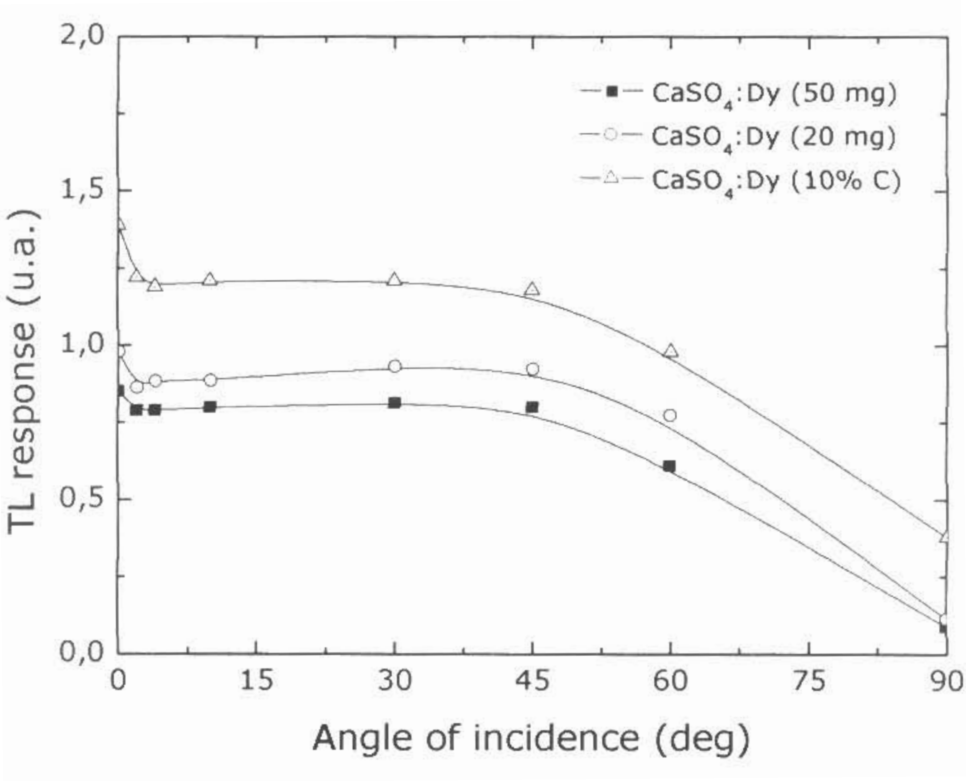
Table 1. Physical characteristics of $CaSO_4$:Dy Teflon pellets.


80 mm
20 mm
320 mm
30 mm
15 mm

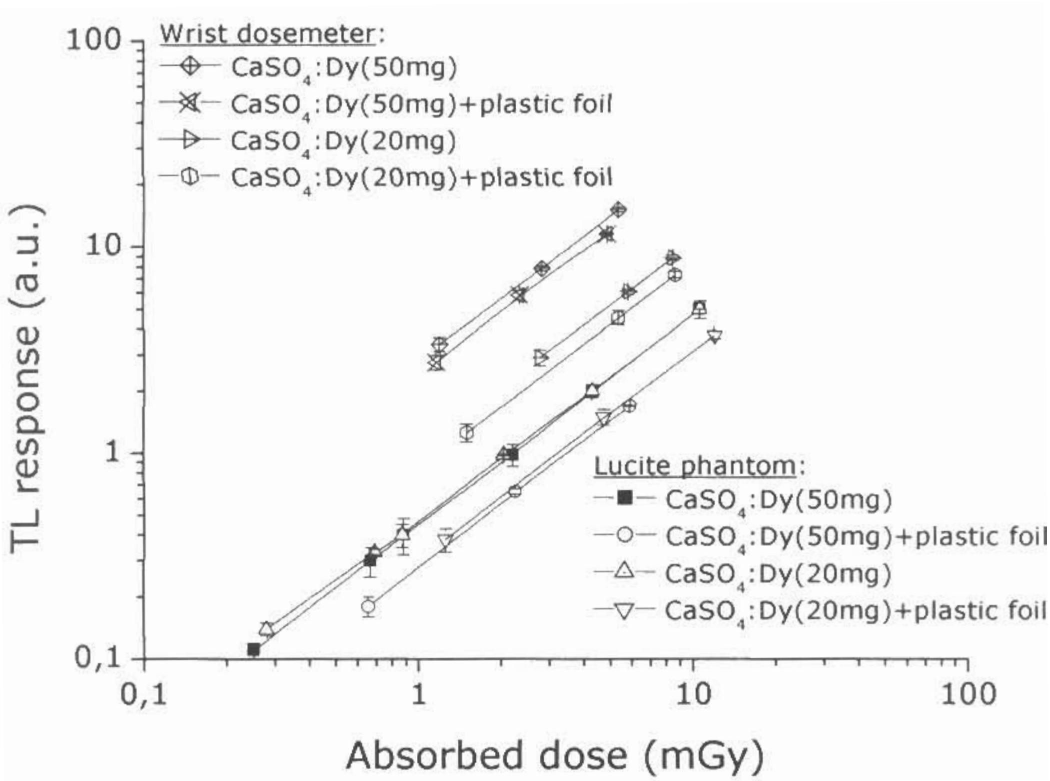


TL response (a.u.)
Absorbed dose (mGy)
CaSO4:Dy (50 mg)
CaSO4:Dy (20 mg)
CaSO4:Dy + 10% C

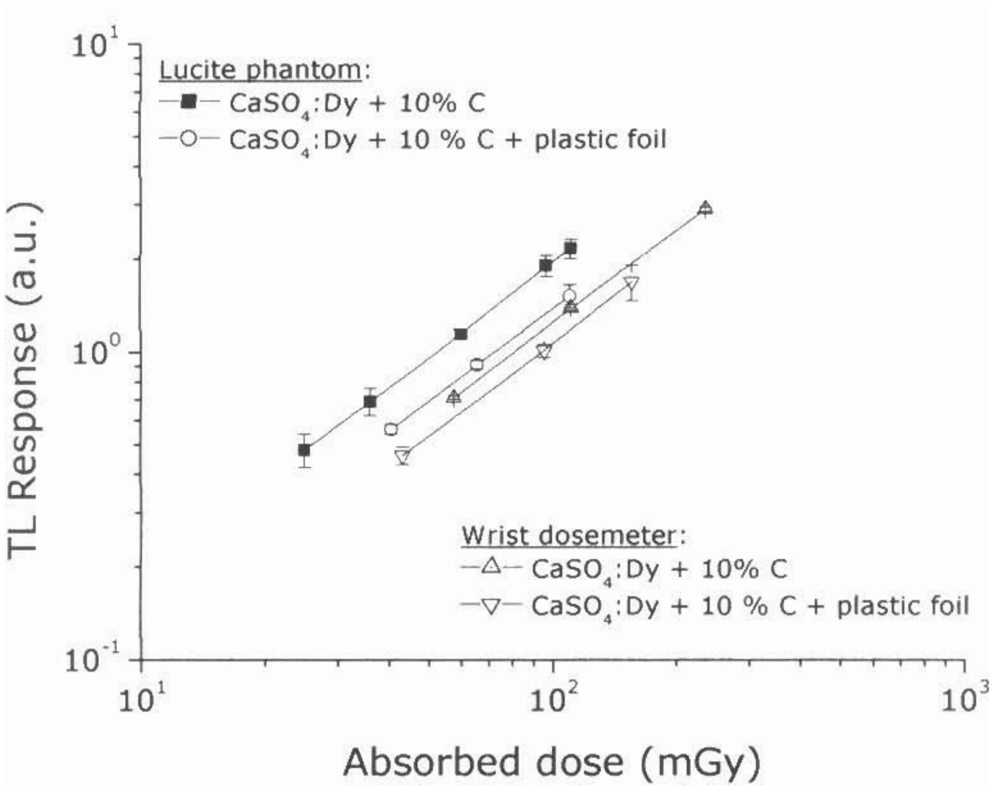

CaSO4:Dy (50 mg)
CaSO4:Dy (20 mg)
CaSO4:Dy (10% C)
TL response (a.u.)
Beta mean energy (MeV)
10^1
10^0
10^-1
10^-2
10^-2
10^-1
10^0
10^1



2,0
1,5
1,0
0,5
0,0
TL response (u.a.)
0
15
30
45
60
75
90
Angle of incidence (deg)
CaSO4:Dy (50 mg)
CaSO4:Dy (20 mg)
CaSO4:Dy (10% C)



100
10
1
0,1
TL response (a.u.)
Wrist dosemeter:
CaSO4:Dy(50mg)
CaSO4:Dy(50mg)+plastic foil
CaSO4:Dy(20mg)
CaSO4:Dy(20mg)+plastic foil
Lucite phantom:
CaSO4:Dy(50mg)
CaSO4:Dy(50mg)+plastic foil
CaSO4:Dy(20mg)
CaSO4:Dy(20mg)+plastic foil
0,1
1
10
100
Absorbed dose (mGy)



Lucite phantom:
CaSO4:Dy + 10% C
CaSO4:Dy + 10 % C + plastic foil
Wrist dosemeter:
CaSO4:Dy + 10% C
CaSO4:Dy + 10 % C + plastic foil
TL Response (a.u.)
Absorbed dose (mGy)

TL Detector	**Mass (mg)**	**Diameter (mm)**	**Thickness (mm)**
$CaSO_4$:Dy	50	6,0	0,8
$CaSO_4$:Dy - Thin	20	6,0	0,2
$CaSO_4$:Dy + 10% C	20	6,0	0,2