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Development of a Extremity Thermoluminescence Dosemeter for Photon Dose Equivalent Assessment

L. L. Campos, R. N. Carvalho
Instituto de Pesquisas Energéticas e Nucleares – CNEN/SP
Travessa R, nº.400 CEP-05508 – 900 São Paulo SP Brazil
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INTRODUCTION

If de dose to any part of the extremities of a worker is likely to exceed three tenths of the annual dose limit on a pro rata basis an additional dosemeter of appropriate design should be worn on a part of the extremity where the dose is expected to have its highest value (1).

An extremity dosemeter is one, which is worn on extremity, that is hand, forearm, foot or ankle, when the extremity may become the limiting organ or tissue. Most often monitoring of the extremities will involve the hand and in particular the finger tips. Such dosemeter has to be worn in addition to a whole-body dosemeter.

Thermoluminescent dosemeters are almost invariably used for extremity dosimetry. They often consist of one thin tissue equivalent detector, which can be worn reasonably at the position likely to receive the maximum dose.

The Instituto de Pesquisas Energéticas e Nucleares IPEN of the National Commission of Nuclear Energy (CNEN), Brazil, developed an individual dosemeter based on $CaSO_4$:Dy thermoluminescent (TL) detectors (2), which were also developed at IPEN (3,4) and are at present produced by the same Institute. This dosemeter was calibrated, in terms of photon dose equivalent, in the Calibration Laboratory of IPEN, and is able to assess this quantity, in the energy range 20 – 1250 keV, with a maximum uncertainty of ± 35% (2). This dosemeter was also calibrated in terms of personal dose equivalent Hp(10) and Hp(0.007) (5) within acceptable uncertainty limits, in the rang 17- 1250keV.

Recently, to replace the extremity film badge to TL badge, was also developed an extremity thermoluminescence dosimeter based on $CaSO_4$:Dy pellets to be worn as wristlct by technicians who work with unsealed sources or handle radioactive materials.

DESCRIPTION OF THE DOSEMETER

The dosemeter design is very simple, the main subject was to develop the mathematical procedure necessary to obtain the dosemeter response. The system consists of two pieces of polyethylene with dimensions of 40mm x 20mm x 10mm that can be superimposed and are able to accommodate three detectors, which are discs of $CaSO_4$:Dy plus Teflon (PTFE) with a diameter of 6.0mm and a thickness of 0.8mm. Due to the effective atomic number of the $CaSO_4$:Dy (15.3) it was necessary to introduce metallic filters to obtain photon energy independence TL response so, one detector is placed between plastic filters of 3.0mm thickness that guarantees electronic equilibrium for ^{60}Co gamma rays. Another detector is located between 1.0mm thick lead and 3.0mm thick plastic filters that provide a cut off in the 100 keV region and a uniform response above this energy. A third detector is sandwiched between filters of lead with thickness of 0.8mm with a central hole of 2.0mm diameter and plastic of 3.0mm thickness, that provides a nearly energy independent TL response from 20 to 1250 keV. The detectors are sealed in a plastic film 20 mg.cm^{-2} thick. All TL detectors are in contact with filters. The filter area is a little larger than the TL detector.

EXPERIMENTAL PROCEDURES

The TL detectors were evaluated in a Harshaw system 5500. The pre-annealing procedure adopted was 300 °C for 1 h. The $CaSO_4$:Dy TL glow curves were integrated between 150 and 300 °C. Individual sensitivity factors were used to normalise the detector TL responses. TL detector individual reproducibilities are better than 3%, considering one standard deviation (1σ) of 10 measurements of the same detector.

The calibration of the dosemeter was carried out with normal incidence irradiations with beam qualities similar to the ISO reference radiations of narrow spectra series generated (6) by a therapy equipment Stabilipan 300 X-ray, with effective energies between 20 and 155 keV. The gamma irradiations were carried out using a ^{60}Co (1 GBq) and a ^{137}Cs (740 GBq) sources.

RESULTS AND COMMENTS

The reproducibility of the dosemeter was investigated studying the effect of repeated heating cycles, irradiation in air, TL reading and annealing. This test was performed with 10 dosemeters used 10 times each. After repeated annealing, irradiation (1mGy) and read out cycles up to 10 times, was always less or equal to 3% (1σ), without any trend with the cycle number.

The calibration of the dosemeter was performed for ^{60}Co gamma doses between 0.1 and 200 mGy. In this range the relationship dose-response is linear.

The energy response of the dosimetric system was evaluated for an energy range between 25 and 670 keV . The response of the TL detectors placed between plastic filters, lead plus plastic and lead with hole plus plastic filters, normalised to ^{60}Co, are presented in Fig. 1.

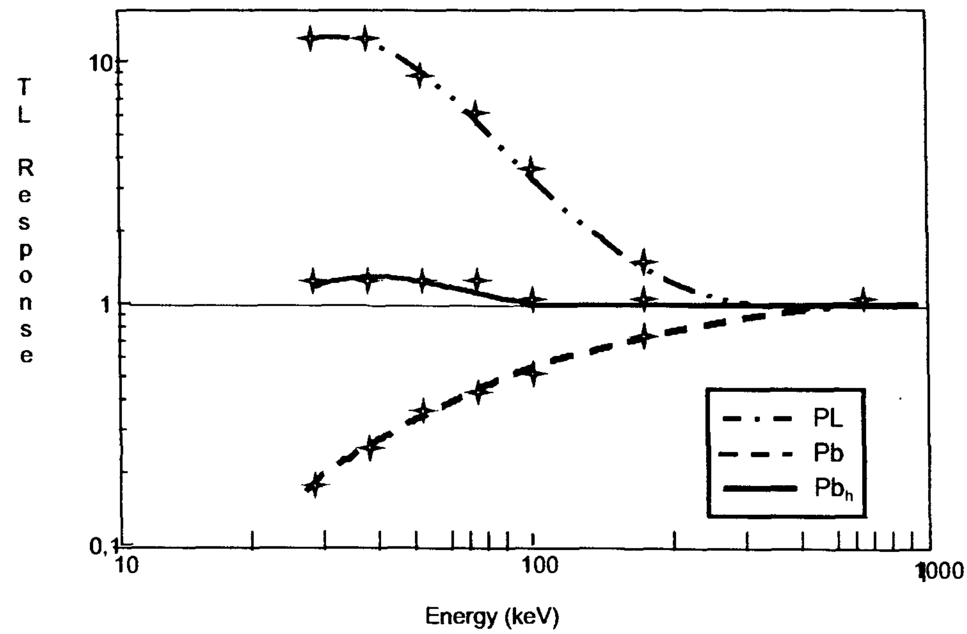

Fig.1 Energy TL response of the IPEN extremity dosemeter.

Ideally, the dosemeter should present a response independent of the photon energy in terms of dose equivalent (H). This is not the case with the IPEN dosemeter, that uses $CaSO_4$:Dy as detector material. In order to achieve a reasonable energy response with this dosemeter in terms of photon dose equivalent a mathematical procedure with the curves of Fig. 1 was looked for.

EFFECTIVE ENERGY DETERMINATION

From Fig.1 it was calculated the ratios between the TL response of the detectors placed between plastic filters (TL_{Pl}) and lead with hole filters (TL_{Pbh}), $\left[\frac{TL_{Pl}}{TL_{Pbh}}\right]$ and the TL readings of the detector placed between lead filters $(TL_{Pb})$and lead with hole filters (TL_{Pbh}), $\left[\frac{TL_{Pb}}{TL_{Pbh}}\right]$ for each energy. With this values were obtained the curves C_{Pl} and C_{Pb} respectively, as a function of the incident energy. The fitting of these two curves provides two functions, E_{Pl} and E_{Pb}, these functions allow the calculation of incident energy knowing the dosemeter TL readings.

$$E_{Pl} = 10^{\left[-10.05*\log\left(\frac{TL_{pl}}{TL_{Phf}}\right)^5 + 28.66*\log\left(\frac{TL_{Pl}}{TL_{Phf}}\right)^4 - 32.03*\log\left(\frac{TL_{Pl}}{TL_{Phf}}\right)^3 + 17.39*\log\left(\frac{TL_{Pl}}{TL_{Phf}}\right)^2 - 5.23*\log\left(\frac{TL_{Pl}}{TL_{Phj}}\right) + 2.82\right]} \quad (1)$$

$$E_{Pb} = 10^{\left[-11.49*\log\left(\frac{TL_{Ph}}{TL_{Phf}}\right)^5 - 20.37*\log\left(\frac{TL_{Ph}}{TL_{Phf}}\right)^4 - 7.02*\log\left(\frac{TL_{Ph}}{TL_{Phf}}\right)^3 + 5.19*\log\left(\frac{TL_{Pb}}{Tl_{Phf}}\right)^2 + 4.55*\log\left(\frac{TL_{Ph}}{TL_{Phf}}\right) + 2.82\right]} \quad (2)$$

The effective energy is given by:

$$E = \frac{E_{Pl} + E_{Pb}}{2}$$

DOSE DETERMINATION

After the determination of the effective energy a calculation methodology was established to obtain H by means of algorithms that would provide energy correction factors (FC). The algorithms were obtained from Fig.1, making the fitting of the TL response curves of the detectors placed between plastic and lead and lead with hole filters for each energy. It was necessary to take two energy intervals to provide the best adjustment: in the first one $E \leq 140keV$, and in the second one $E > 140keV$. The resulting factors allow the calculation of H knowing the effective energy.

If $E \leq 140keV$

$$FC_{Pl} = 10^{\left[-3.69*\log(E)^5 + 35.64*\log(E)^4 - 133.44*\log(E)^3 + 241.00*\log(E)^2 - 209.97*\log(E) + 71.76\right]} \quad (4)$$

$$FC_{Pb} = 10^{\left[3.05*\log(E)^5 - 30.71*\log(E)^4 + 122.28*\log(E)^3 - 241.42*\log(E)^2 + 237.71*\log(E) - 94.49\right]} \quad (5)$$

If $E > 140keV$

$$FC_{Pl} = 10^{\left[-1.09*\log(E)^3 + 9.32*\log(E)^2 - 26.41*\log(E) + 24.89\right]} \quad (6)$$

$$FC_{Pb} = 10^{\left[-0.08*\log(E)^3 + 0.31*\log(E)^2 + 0.19*\log(E) - 1.28\right]} \quad (7)$$

were $FC_{Pl} and FC_{Pb}$ are the correction factor for the detectors placed between plastic and lead filters respectively.

In the case of the detectors placed between lead with hole filters:

If $E \leq 100keV$

$$FC_{Pbh} = 10^{\left[-1.42*\log(E)^5 + 12.40*\log(E)^4 - 40.87*\log(E)^3 + 62.04*\log(E)^2 - 41.24*\log(E) + 8.31\right]} \quad (8)$$

If $E > 100keV$

$$FC_{Pbh} = 1 \quad (9)$$

were

FC_{Pbh} is the correction factor for the detectors placed between lead with hole filters.

Finally the H value is given by the average of the H_{Pl}, H_{Pb}, H_{Pbh} values,

$$H = \frac{H_{Pl} + H_{Pb} + H_{Pbh}}{3}$$

where:

$$H_{Pl} = \frac{TL_{Pl} * FC * FD}{FC_{Pl}} \qquad H_{Pb} = \frac{TL_{Pb} * FC * FD}{FC_{Pb}} \qquad H_{Pbh} = \frac{TL_{Pbh} * FC * FD}{FC_{Pbh}}$$

and

Fc = calibration factor (mSv / nC)

FD = Fading correction factor

The performance of the dosemeter was evaluated for different X ray spectra and angles of radiation incidence, although the dosemeter is not designed to identify radiation incidence angles, using the equations above. The obtained results are presented in Fig. 2, where the accuracy limits are given (7) for individual monitoring.

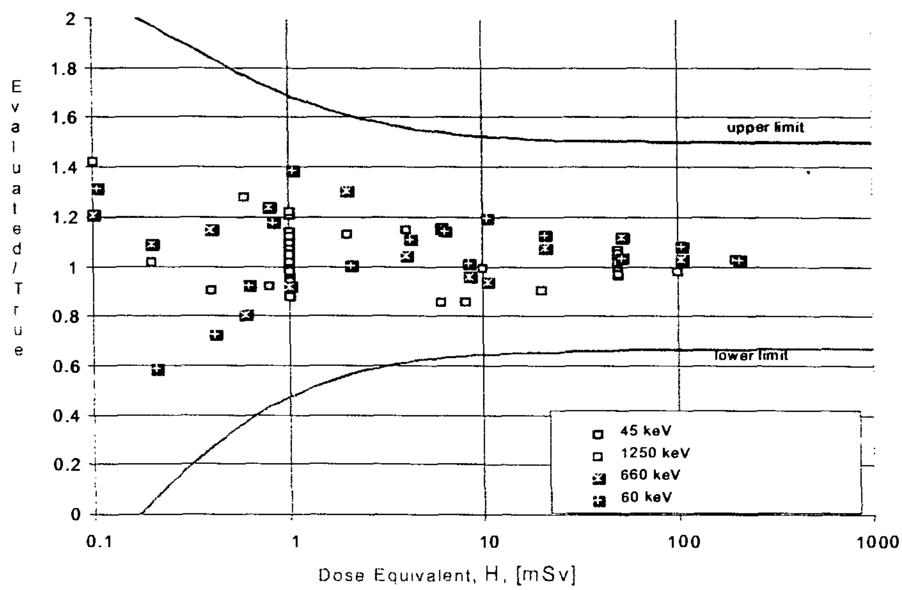

Fig. 2 Accuracy limits for dose and experimental validation data.

CONCLUSION

This system permits photon dose equivalent assessment as well as the effective energy determination. The present evaluation method used for the dosemeter is not applicable to mixed photon-beta fields.

Taking into account the results obtained we conclude that the proposed dosimetric system agrees with the requirements for its application as extremity monitoring system and the applied methodology can be used for any multi – element dosimetry system.

ACKNOWLEDGEMENTS

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REFERENCES

1- P. Christensen, H. W. Julius; T. O. Marshall, *Technical Recommendations for Monitoring Individuals Occupationally Exposed to External Radiation.* Radiation Protection 73 report EUR 14852 EN 1994.

2- L. L. Campos, *Preparation of $CaSO_4$:Dy Single Crystals* . J. Lum. 24, 481-483 (1983).

3- L. L. Campos, and M. F. Lima, *Dosimetric Properties of $CaSO_4$:D_Y Teflon Pellets Produced at IPEN.* Rad. Prot. Dosim. 14(4), 333-335 (1986).

4- T. A. Da Silva, ; L. L. Campos, and L. A. R. da Rosa, *Novo Porta-Dosímetro Nacional para Detectores TL de $CaSO_4$:Dy.* I Encontro Nacional de Aplicações Nucleares Pernambuco, Brazil, 27-30 May 1991. Anais 1, 71-82 (1991)

5- T. A. Da Silva ; L. L. Campos, and L. A. R da Rosa, *Thermoluminescent Dosemeter for Personal Dose Equivalent Assessment.* Rad. Prot. Dosim. 58 (1) 17-21 (1995).

6- International Organization for Standardization. *X and Gamma Reference Radiations for calibrating Dosemeters and Ratemeters and for Determining their Response as a Fuction of Photon Energy. Part 1: Characteristics of the Radiation and their Methods of Production.* Revised text ISSO 4037 (1990).

7- P. Christensen and R. V. Griffith, *Required Accuracy and Dose Thresholds in Individual Monitoring.*

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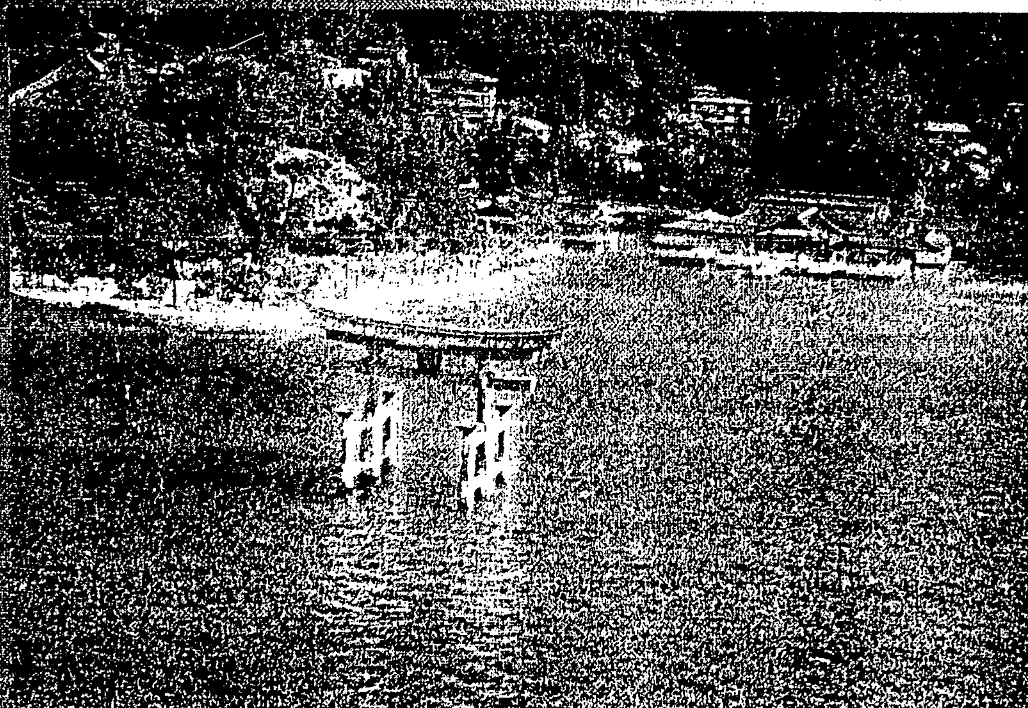

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