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EXPERIMENTAL DETERMINATION OF RELATIVE LIGHT CONVERSION FACTORS OF TLD-100 FOR PROTONS WITH ENERGIES FROM 2.0 TO 9.0 MeV

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1. INTRODUCTION

For the application of TL detectors for the dosimetry in mixed neutron-gamma fields one needs information about the detector sensitivity as a function of neutron energy. For the theoretical calculation of such sensitivities in dependence of neutron energy it is necessary to know several phosphor parameters, from which the so-called light conversion factor f_c is of substantial importance. This factor describes TL efficiency of heavy charged particles in the detector material.

The light conversion factor f_c is defined as the ratio between emitted light energy dE_l and applicated radiation energy dE_r, both related to the same mass element dm:

$$f_c = \frac{dE_l/dm}{dE_r/dm} . \qquad (1)$$

To eliminate parameters of the evaluation equipment it is commonly useful to determine relative light conversion factors η_{ij} defined as the ratio

$$\eta_{ij} = \frac{f_{c,i}}{f_{c,j}} , \qquad (2)$$

where $f_{c,i}$ and $f_{c,j}$ are the light conversion factors for heavy charged particles i and for a reference radiation j. Usually one chooses as reference radiation a weak ionizing radiation like ^{60}Co gamma rays, thus obtaining a macroscopic homogenous irradiation of the thermoluminescent phosphors.

Especially interesting for TL detector sensitivity calculations are relative light conversion factors η_{ij} for heavy charged particles with energies between 0.1 MeV and 15 MeV [1]. Experimental results of the determination of η-values in the last years were reported for alpha particles [2-5], protons and havier charged particles like ^{12}C or ^{18}O [6-8]. The results have shown, that it is impossible to describe the TL efficiency of heavy charged particles by an universal parameter, like for instance the LET of the particle in the radiator material. It is better to determine η for each TL phosphor as a function of kind of the particle and particle energy.

Light conversion factors were also determined by theoretical calculations basing on different models [3,4,9-11]. Because of the commonly insufficient known kind of the interaction effects of the particles with the phosphor material these calculations have almost model character and need an examination by experiment.

2. BASIC CONSIDERATIONS TO THE η-DETERMINATION

For the experimental determination one can from equation (2) derive the expression

$$\eta_{i(j)} = \frac{(M(E)/D)_i}{(M/D)_{^{60}Co}} , \qquad (3)$$

where M_i and $M_{^{60}Co}$ are the TL detector readings after application of the heavy charged particle dose D_i and $D_{^{60}Co}$, respectively. η_i depends on the energy of the incident particle

$$\eta = f(E). \qquad (4)$$

Because of the slowing down of a particle during its passage through the phosphor one must clarify the expression $\eta(E)$ in the following manner:

- We say $\eta(E)$ if the variation of stopping power during the passage through a TL detector of thickness d is lower than 20%.

$$\left| \frac{\frac{dE}{dx}(x=0) - \frac{dE}{dx}(x=d)}{\frac{dE}{dx}(x=0)} \right| \le 0,2 . \qquad (5)$$

- Otherwise we speak of a mean relative light conversion factor $\bar{\eta}(E)$.

- If the maximum range of the particles in the material does not exeed the detector thickness d, we say $\eta_{total}(E)$.

For the determination of the received dose after irradiation of TL materials with particles of kind i and primary energy E the following expressions must be applied:

a) Thin detectors:
("thin" means accomplishment of equation (5))

$$D_i(E) = \rho^{-1} \Phi_i(E) \left(\frac{dE}{dx}(E)\right)_i , \qquad (6)$$

where ρ is the density of the luminescent material, $\Phi_i(E)$ is the particle fluence and $dE/dx(E)_i$ represents the stopping power of the particle i with incident energy E.

b) If condition (5) is not fulfilled in equation (6) $(dE/dx(E))_i$ must be replaced by a mean stopping power value $(\overline{dE/dx(E)})_i$.

$$D_i(E) = \rho^{-1} \Phi_i(E) \left(\overline{\frac{dE}{dx}(E)}\right)_i . \qquad (7)$$

c) If the maximum range of the charged particles $(R_{max}(E)_i)$ is lower than the detector thickness d, then equation (8) is valid.

$$D_i(E) = \rho^{-1} \Phi_i(E) E d^{-1} . \qquad (8)$$

From these basic considerations it follows, that for a dose determination after heavy charged particle bombardment the fluence measurement and the spectrometry of the particle energy is necessary. Furthermore one needs stopping power values as a function of particle energy for the corresponding thermoluminescent material.

For the η determination according to equation (3) also an irradiation with ^{60}Co gamma radiation must be carried out. The thereby received gamma dose and the particle dose must always lie in the linear part of the dose characteristic of the TL phosphor.

Besides, it must be noted that the pre-irradiation treatment and the evaluation of the detector both for gamma irradiation and irradiation with heavy charged particles must be carried out under the same conditions.

3. EXPERIMENTAL

At the Division of Radiation Protection Physics of the University of Technology, Dresden an experimental arrangement for the determination of relative light conversion factors was built up [12]. The arrangement is connected with an experimental drain of the Rossendorf tandem accelerator EGP-10. The TL detectors were placed by a sluice system in a recipient where irradiation goes on by a pressure of $2 \cdot 10^{-3}$ Pa.

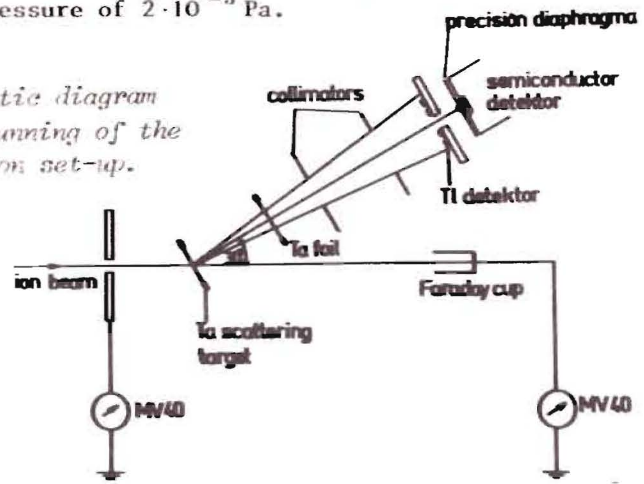


Fig. 1. Schematic diagram of the beam running of the ion irradiation set-up.

In fig.1 the schematic diagram of beam running is shown. An ion beam from the tandem generator well collimated by the entrance diaphragm is focussed on a 5 μm thick tantal scattering foil. The major part of ion beam is stopped in a Faraday cup. Diaphragm and Faraday cup are used for justage of the primary beam. As a result of Rutherford scattering in the first tantal target at the place of irradiation an approximate homogenous irradiation field is obtained with such low intensities which enable the fluence measurement and the spectrometry of the particle energy. A second 5 μm thick tantal target decreases the partition of inelastic scattered heavy charged particles. By the aid of a collimator system a rectangular particle incidence is guaranteed on TL detectors and semiconductor detector. The latter serves for irradiation field spectrometry. The variation of particle energy is realized by the change of the accelerator voltage of the tandem generator.

to the fluence measurement

On the Si(Li) semiconductor detector placed immediatly behind an aperture of the plate carrying the TL detectors a precision diaphragm is fixed. The geometrical conditions are showing in fig. 2.

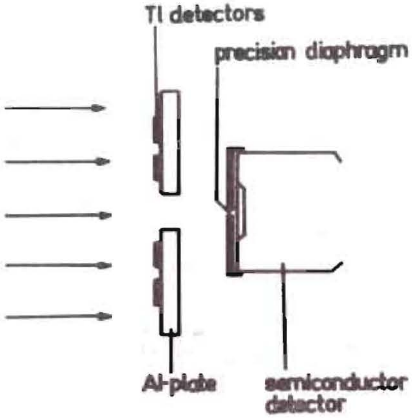
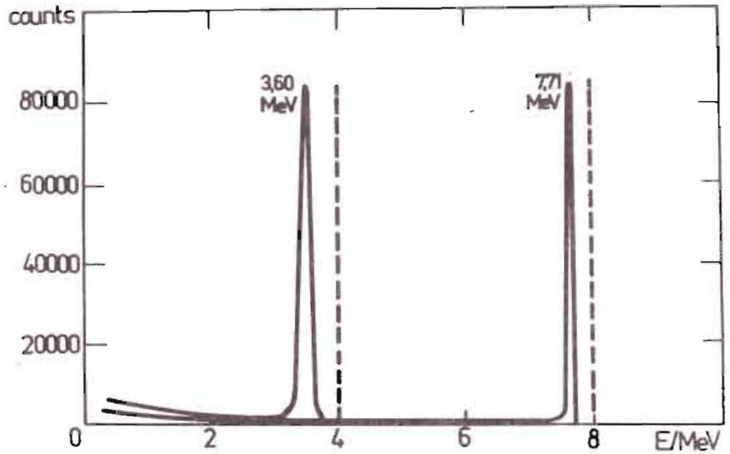


Fig. 2. Geometrical conditions at the place of TL detector irradiation.

Fig. 3. Examples of measured energy spectra of primary 4 MeV- and 8 MeV - ions at the irradiation place.



The fluence according to this arrangement is given by

$$\Phi = f_{geom} \frac{Z}{A} \quad (9)$$

with Z is the registered Si(Li) detector pulses, A is the aperture area of the precision diaphragm and f_{geom} is a geometrical correction factor.

Through interactions of the ions within the tantal foils one doesn't measure a Dirac energy distribution at the irradiation place. Fig.3 shows two examples of measured spectra. That is why for the purpose of dose calculation it is necessary to part in the spectrum in a number of energy groups k (k=group number, in this case k running from 1 to 256 is favourable). Therefore the expressions for dose calculations after heavy charged particle irradiation (eqs. 6-8) are modified to (10-12).

$$D_i(E) = (\rho\cdot A)^{-1} f_{geom} \sum_{k=1}^{256} z_k (dE/dx(E_k))_k \quad (10)$$

$$D_i(E) = (\rho\cdot A)^{-1} f_{geom} \sum_{k=1}^{256} z_k (dE/dx(E_k))_k \quad (11)$$

$$D_i(E) = (\rho\cdot A\cdot d)^{-1} f_{geom} \sum_{k=1}^{256} z_k E_k \quad (12)$$

to the electronic evaluation equipment

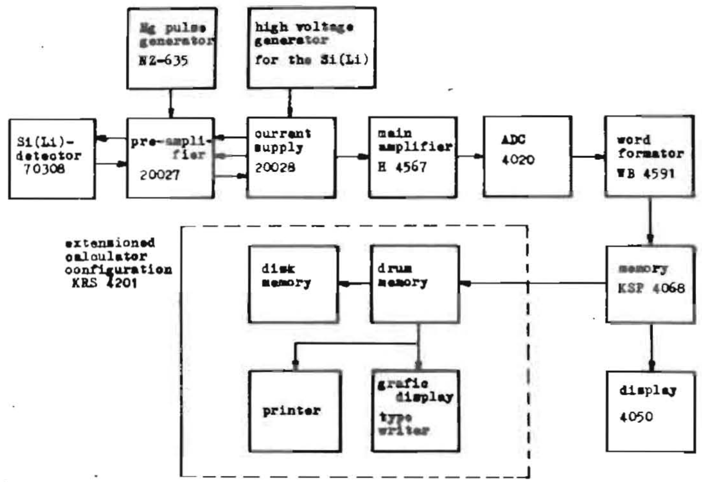


Fig. 4. Electronic evaluation equipment.

In fig.4 the substantial implements of the electronic evaluation equipment are shown. This equipment allows

- energy calibration of the measuring assesment by means of a ^{241}Am alpha source and a mercury pulser;
- death time correction using the "pulse method";
- read out of the measured spectrum in a dialog traffic with the calculator configuration KRS 4201. That means data transfer to a disc memory and dose calculation with the developed programme ETA (thereby scaling of the measured spectrum with the stopping power function, correction of death time, gamma background correction and so on).

The stopping power values for several TL materials were got by the aid of the calculation programme STOPOW 82 [13]. The agreement between experimentally determined dE/dx -values for protons and deuterons in TL materials and such calculated with STOPOW 82 is very good [14].

to the gamma irradiation

During gamma irradiation on a high dose measuring facility the TL detectors were placed between 10 mm thick PMMA plates. The dose in air was determined with a scaled reference normal.

to the TL evaluation

For the evaluation a Hungarian TL reader NHZ-203 connected with a microcalculator was used. The measuring signal coming from the TL reader thereby is digitalised and transferred to the working memory of the calculator. By this from one measurement one gets a lot of information and the evaluation according to the peak height method and the peak area method between variable temperature limits is possible. The pretreatment conditions - as already mentioned it must be the same in both irradiation cases - are: heating 1 hour at a temperature of 300°C, storage in dark slights and TL evaluation within 5 days after irradiation.

4. RESULTS

Total light conversion factors η_{total} were determined for LiF: Mg, Ti in the form of hot pressed chips (TLD-100 from the HARSHAW Chemical Company). For this purpose irradiations were realized with protons in the energy range from 2.0 to 9.0 MeV. In each case 6 detectors were irradiated with particles of the same energy and evaluated for the determination of one η value.

Table 1. Evaluation parameters and considered TL properties

TL detector	heating rate $(K \cdot s^{-1})$	T_{end} (°C)	measuring time t_{mes} (sec.)	considered TL peaks (°C)	temperature limits for peak area method (°C)
TLD - 100 (density $\rho = 2.64 g cm^{-3}$)	4	320	80	230 (peak V) 300 (peak VI)	130 - 320

Table 2. Total light conversion factors of TLD-100 as a function of the proton energy E_p

E_p in MeV	η total integral acc. peak area method	η total peak V	η total peak VI
2,69	0,39 ± 0,03	0,37 ± 0,03	2,92 ± 0,30
3,77	0,43 ± 0,04	0,41 ± 0,04	2,55 ± 0,32
4,83	0,49 ± 0,05	0,47 ± 0,05	2,41 ± 0,25
5,87	0,53 ± 0,05	0,51 ± 0,05	2,35 ± 0,27
7,39	0,58 ± 0,06	0,55 ± 0,06	2,37 ± 0,24
8,41	0,64 ± 0,06	0,63 ± 0,06	2,08 ± 0,21

In table 1 the evaluation parameters and considered TL properties are listed. Table 2 shows the results of the determination of total relative light conversion factors. In fig. 5 η_{total} for peak V and VI and η_{total} determined according to the peak area method versus proton energy can be seen. The measuring uncertainties were estimated to be 10%. The reproducibility is better than 5%.

Summarizing one can conclude:

a) With increasing proton energy as well as η_{total} determined according to the peak area method as η_{total} for peak V are growing. The values are below 1.

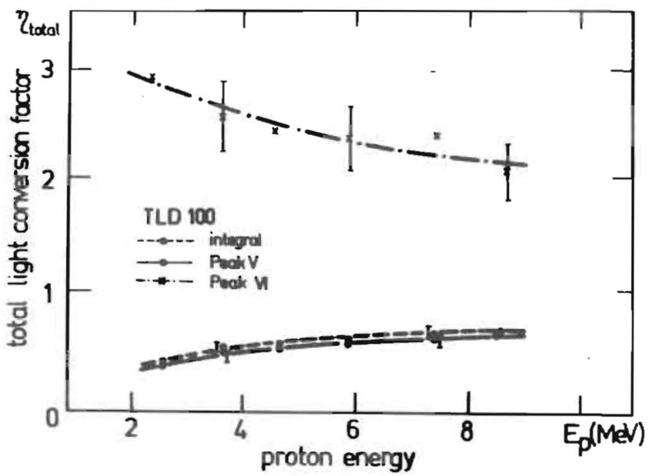


Fig. 5. Total light conversion factor $\eta_{total} = f(E_p)$, *comparison between integral* η*-value and* η *for peak V and VI (detector: TLD-100).*

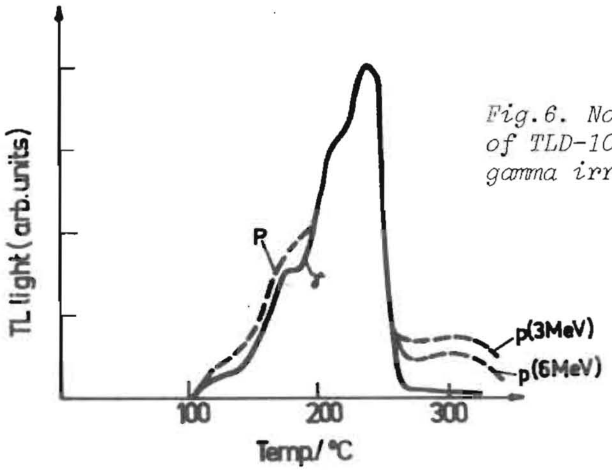


Fig. 6. Normalized glow curves of TLD-100 after proton and gamma irradiation.

b) η_{total} for peak VI shows a contrary energy dependence. The values clearly exceed 1.

A comparison between normalized TL glow curves of TLD-100 after proton and gamma irradiation is shown in fig.6. It is obvious, that after proton irradiation peak VI is more predominant, obtaining for this peak values greater than 1. Also low temperature peaks (175 °C) are distinctly expressed. A shifting of glow peak positions after proton irradiation compared with the positions after gamma irradiation within the measuring accuracy couldn't be observed.

The η values measured in this work are insignificant below those measured by JAHNERT [4]. Relative light conversion factors for peak VI greater than 2 were reported by WALIGORSKI [15] basing on his theoretical calculations.

5. CONCLUSIONS

According to the presented method and with the developed irradiation arrangement it is possible to determine relative light conversion factors with sufficient accuracy. The whole equipment can also be used to measure η values for deuterons, alpha particles and heavier charged particles with energies of some MeV/nucleon. These experiments are under preparation. Also under preparation is the development of extreme thin TL detectors to determine relative light conversion factors.

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Экспериментальное определение относительного светового выхода ТЛД-100 для протонов с энергией от 2 до 9 МэВ

Относительный световой выход /О.С.В./ для тяжелых заряженных частиц /протоны, дейтоны, ядра отдачи/ необходимо знать для вычисления чувствительности к нейтронам ТЛ-детекторов. В данной статье представлен экспериментальный метод определения О.С.В. Описанная экспериментальная установка дает возможность облучения различных образцов люминофоров тяжелыми заряженными частицами и определения потока и спектрометрии частиц в то же самое время.

Для определения О.С.В. необходимо было знать дозы, применяемые, соответственно, при облучении γ-квантами и тяжелыми заряженными частицами, и соответствующие показания детекторов при определении термолюминисценции. Обсуждаются проблемы, возникающие при определении дозы.

На этой экспериментальной установке был определен О.С.В. для ТЛД-100 при облучении протонами. Представлены и обсуждаются О.С.В., полученные как по методу суммарного световыхода, так и по методу взвешенных пиков.

Работа выполнена в Отделе радиационной безопасности и радиационных исследований ОИЯИ.

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Experimental Determination of Relative Light Conversion Factors of TLD-100 for Protons with Energies from 2.0 to 9.0 MeV

Relative light conversion factors (R.L.C.F.) for heavy charged particles (protons, deuterons, recoils) are needed for the calculation of the neutron sensitivity of TL detectors. Such light conversion factors can be determined experimentally.

In the given paper a method is represented for the experimental determination of R.L.C.F. The described experimental arrangement gives the possibility of the irradiation of different luminophor samples with heavy charged particles and flux determination and particle spectrometry at the same time. For the determination of R.L.C.F. the doses are needed which are applicated at the irradiation with heavy charged particles and gamma radiation, respectively, and the according detector readings at the TL evaluation. The problems arising at the dose determination are discussed. With this experimental arrangement R.L.C.F. for TLD-100 for protons were determined. The relative light conversion factors determined according to the light sum method as well as the peak height method are summarizingly represented and discussed. Furthermore a comparison of the glow curves is made after gamma and proton irradiation.

The investigation has been performed at the Department of Radiation Safety and Radiation Researches, JINR.

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