сообщения
объединенного
института
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исследований
дубна

E16-83-879

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CALCULATION AND EXPERIMENTAL DETERMINATION OF THE FAST NEUTRON SENSITIVITY OF OSL DETECTORS WITH HYDROGEN CONTAINING RADIATOR

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1983

1. INTRODUCTION

The use of detectors based on the optically stimulated luminescence (OSL) for the dosimetry of fast neutrons has some advantages over thermoluminescence (TL) detectors [1,2]. Especially the extremely low thermal stress during stimulation with light allows the embedding of the luminophor in hydrogen containing materials (principle of mixed radiators). That is why there is no need for the separation of radiator and luminophor before the evaluation as it is necessary, e.g., in the case of TL detectors [3].

This paper deals with a procedure for the calculation of the neutron sensitivity of such OSL detectors; the calculated results are compared with experimentally determined sensitivities.

2. CALCULATION OF THE NEUTRON SENSITIVITY

In principle the procedure for the calculation of the neutron sensitivity of OSL detectors is analogous to that for TL detectors described in [4]. The neutron sensitivity is defined as the ratio

$$m(E) = \frac{M(E)}{\Phi} \qquad (1)$$

with $M(E)$ as the detector reading caused by neutrons of the energy E and Φ as the neutron fluence. $m(E)$ is divided into two independent components (valid for free-air conditions):

$$m(E) = m_D(E) + m_R(E). \qquad (2)$$

$m_D(E)$ is the sensitivity component caused by the interaction of the primary neutrons with the phosphor atoms and $m_R(E)$ is the component caused by charged particles which comes out from the hydrogen containing radiators. As is shown in [4], the calculation is independent of the evaluation equipment by using the gamma sensitivity m of the detectors:

$$m(E) = m'_{\gamma}[f_D(E) + f_R(E)]. \qquad (3)$$

Calculation of $f_D(E)$

This component is analogously calculated for TL phosphors. This is justified because: first, no differences between TL and OSL phosphors have to be expected and second, this component makes only a small contribution to the sensitivity for fast neutrons. For comparison with experimental results values were taken from [5].

Calculation of $f_R(E)$

The calculation of this sensitivity component was carried out for a detector arrangement which is schematically represented in fig.1. The luminophor is embedded in a hydrogen containing material and this detector is covered by a contact radiator.

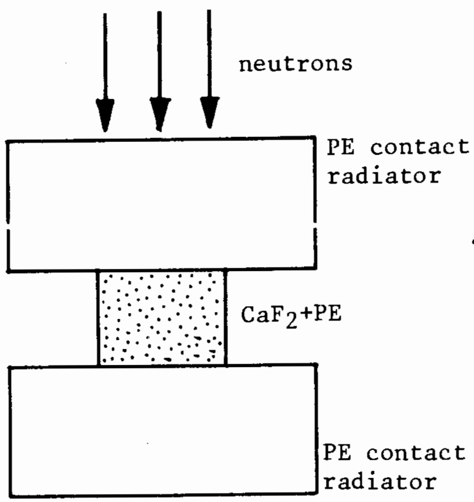
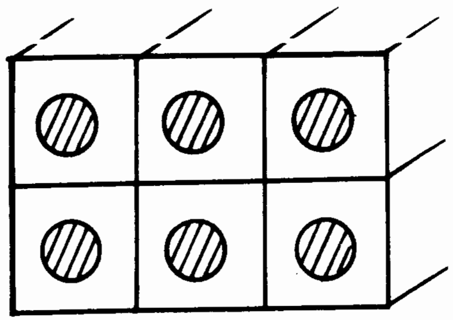


Fig.1

Fig.2



Calculations for such a geometrical arrangement are very complicated. Therefore some simplifications are used which have no essential influence on the accuracy of the calculations:

- The naturally given disordered distribution of the phosphor grains is replaced by an ordered, homogeneous distribution (for easier mathematical formulation of the problem).
- It is supposed that phosphor grains are spheres with a unit mean diameter.

Table 1

Calculated neutron sensitivities of CaF_2:Mn -polyethylene-detectors for various luminophor containing. Calculation parameters were: mass density of luminophor and radiator 3.15 g/cm^3 and 0.93 g/cm^3; mass part of luminophor in the mixture: 30, 20 and 10%; luminophor grain size 35 μm; sensitive layer thickness 500 μm; contact radiator thickness 2.5 mm.

I	E in MeV	$f_R(E)$ in Gy/cm^{-2}			FSD * for 20% calculation
		30%	20%	10%	
1	15.0	4.28-11	4.37-11	4.47-11	0.03
2	14.7	4.29-11	4.32-11	4.33-11	0.01
3	12.0	4.06-11	4.24-11	4.29-11	0.01
4	10.0	3.93-11	4.05-11	4.17-11	0.01
5	9.0	3.79-11	3.97-11	4.02-11	0.01
6	8.0	3.56-11	3.74-11	3.79-11	0.01
7	7.0	3.34-11	3.54-11	3.62-11	0.01
8	6.0	2.88-11	3.09-11	3.30-11	0.01
9	5.5	2.63-11	2.77-11	3.02-11	0.01
10	5.0	2.38-11	2.54-11	2.65-11	0.01
11	4.0	1.87-11	1.95-11	2.05-11	0.01
12	3.2	1.39-11	1.45-11	1.43-11	0.01
13	2.5	9.34-12	9.76-12	1.03-11	0.02
14	2.0	6.16-12	6.81-12	6.97-12	0.02
15	1.5	3.37-12	3.36-12	3.42-12	0.03
16	1.0	1.36-12	1.32-12	1.41-12	0.04
17	0.6	2.91-13	2.90-13	3.15-13	0.06
18	0.1	2.63-14	2.38-14	1.87-14	0.13

*FSD - fractional standard derivation, remarks: the statistics for 20% is better than for 10% and a little worse than for 30%.

- Phosphorus grains are placed space centred in cubic cells; the detector itself consists of a dense packing of these space cells, which are placed translation symmetrically (see fig.2).

- Using the neutron interaction only first collision effects are considered. This assumption is justified for the investigated detectors of thicknesses between 300 μm and 1 mm because only about 1 of 100 neutrons interacts. Based on these suppositions a Monte-Carlo programme MIXRAD/83/ (see /6/) was developed which permits the calculation of the sensitivity component $f_R(E)$.

The following input parameters are necessary:

- Cross sections for the elastic neutron-proton scattering (calculated according to ref. /7/),
- stopping power and range of recoil protons (calculated with the aid of the computer programme STOPOW/82 (see /8/),
- relative light conversion factors for protons (taken from /9/).

The results for three different OSL-detector-radiator combinations are given in table 1.

3. EXPERIMENTAL DETERMINATION OF THE NEUTRON SENSITIVITY

The neutron sensitivity was experimentally determined for CaF_2:Mn -polyethylene detectors. In order to eliminate the influence of gamma radiation in the different radiation fields at the same time CaF_2:Mn-PTFE detectors were irradiated. The detector reading for the detectors under investigation is

$$M(E) = m'_\gamma D_\gamma + M(E)\Phi \qquad (4)$$

and

$$M(E)^* = m^*_\gamma \frac{(\mu_E/\rho)^*}{(\mu_E/\rho)} D_\gamma + m(E)^*\Phi \qquad (5)$$

for the CaF_2:Mn-PTFE detectors (all quantities referring to this are marked with*). μ_E/ρ is the mass-energy absorption coefficient and D_γ the absorbed dose of gamma radiation measured with the CaF_2:Mn -polyethylene detector. By solving the equation systems (4) and (5) one gets the neutron sensitivity m(E). m(E)* is calculated /5/; the incorrectness of this quantity has no essential influence on m(E).

The production of the CaF_2:Mn -polyethylene detectors is described in /1,10/. For the evaluation of the detectors a convenient equipment was developed /2/.

The experimental determination of the neutron sensitivity was carried out at three different neutron sources:

- (d,D) generator of Technical University Dresden (E = = 3.2 MeV),
- cyclotron U-200 of ZfK Rossendorf (mean energy of fast neutrons $\bar{E}$ = 5.7 MeV /11/),
- (d,T) -generator of Technical University Dresden (E = = 14.7 MeV).

4. RESULTS AND DISCUSSION

The experimentally determined and calculated neutron sensitivities of the investigated detectors are given in table 2.

Table 2

Calculated and experimentally determined neutron sensitivities of CaF_2:Mn -polyethylene detectors (marking of the detectors in column 2: phosphor content in mass - % (thickness in μm).

E in MeV	detectors	$f_R(E)$ in Gy/cm^{-2}	$f_D(E)$ in Gy/cm^{-2}	$m_n(E)_{cal}$ in nc/cm^{-2}	$m_n(E)_{exp}$ in nc/cm^{-2}
3.2	10/500	1.43 -11	6.14 -13	0.53 -10	0.62 -10
	20/500	1.45 -11	6.14 -13	1.43 -10	1.64 -10
	30/500	1.39 -11	6.14 -13	2.25 -10	2.25 -10
5.8	10/500	3.13 -11	3.13 -12	1.22 -10	1.08 -10
	20/500	2.9 -11	3.13 -12	3.03 -10	2.92 -10
	30/500	2.73 -11	3.13 -12	4.73 -10	4.17 -10
14.7	10/500	4.39 -11	6.71 -12	1.79 -10	1.88 -10
	20/500	4.32 -11	6.71 -12	4.72 -10	4.50 -10
	30/500	4.29 -11	6.71 -12	7.70 -10	6.64 -10

Gamma-sensitivities m'_γ

Detectors:		
	10/500:	3.54±0.15 nC/Gy
	20/500:	9.45±0.43 nC/Gy
	30/500:	15.53±0.85 nC/Gy
	50/800:	43.8±4.1 nC/Gy

It can be seen that there is a good agreement between theoretical and experimental results. The maximum error in experimental determination amounts to 20%, 12% of which results from the error of the fluence determination.

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Received by Publishing Department
on December 22,1983.

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Феллингер Ю., Хеннигер Ю., Хюбнер К. E16-83-879

Расчет и экспериментальное определение чувствительности к быстрым нейтронам ОСЛ-детекторов с водородосодержащим радиатором

Детекторы, основанные на оптически стимулируемой люминесценции, полезны для дозиметрии быстрых нейтронов. Для этого необходимо знать чувствительность этих детекторов. Описана методика вычисления чувствительности к нейтронам. Для CaF_2:Mn, внедренного в полиэтилен, вычисленные значения сравнивались с экспериментально определенными чувствительностями к нейтронам. Согласие хорошее.

Работа выполнена в Отделе радиационной безопасности и радиационных исследований ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна 1983

Fellinger J., Henniger J., Hübner K. E16-83-879

Calculation and Experimental Determination of the Fast Neutron Sensitivity of OSL Detectors with Hydrogen Containing Radiator

Detectors based on the optically stimulated luminescence are useful for fast neutron dosimetry. For that one needs the neutron sensitivity of these detectors. It is described a procedure for the calculation of the neutron sensitivity. For CaF_2:Mn embedded in polyethylene the calculated values are compared with experimentally determined neutron sensitivities. There is a good agreement.

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

Communication of the Joint Institute for Nuclear Research. Dubna 1983