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INFLUENCE OF DIFFERENT DETECTOR PARAMETERS ON THE NEUTRON SENSITIVITY OF OSL-DETECTORS

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1. INTRODUCTION

The dosimetry in mixed neutron gamma fields with the aid of the optically stimulated luminescence (OSL) has some advantages in comparison with the thermally stimulated luminescence (TSL) because during the optical evaluation of the detectors the thermal stress is very low [1-3]. For that reason an embedding of the luminophor material in hydrogen containing matrix substances is possible without problems.

For the calibration of dosimeters based on the OSL in mixed neutron gamma fields the knowledge of the neutron sensitivity $m(E)$ of different detectors is necessary. This sensitivity is defined as the ratio between the detector reading $Q(E)$ caused by an irradiation with neutrons of the energy E and the neutron fluence Φ according to equation (1):

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

For the theoretic determination of $m(E)$ it is favourable to separate the neutron sensitivity in different, independent items:

$$m(E) = m_D(E) + M_{n,\gamma}(E) + m_A(E) + m_R(E), \qquad (2)$$

$m_D(E)$ is the sensitivity component caused by the interaction of the primary neutrons with the phosphor atoms, $m_{n,\gamma}(E)$ is the sensitivity part, which is caused by secondary gamma rays from the human body, $m_A(E)$ is the sensitivity component in consequence of the interaction of albedo neutrons with the detector material, and $m_R(E)$ is the component caused by charged particles which come from the hydrogen containing radiators. By using the gamma sensitivity of the detector related to the absorbed gamma dose $m'\gamma$ one gets the neutron sensitivity according to equation (3) [4,5]:

$$m(E) = m'\gamma \{ f_D(E) + f_{n,\gamma}(E) + f_A(E) + f_R(E) \}. \qquad (3)$$

The items of the second factor are calculable from the investigations of the radiation transport. In this paper the influence of different detector parameters on the neutron sensitivity of $CaF_2:Mn$ -polyethylene-OSL detectors are investigated systematically. The components $f_D(E)$, $f_{n,\gamma}(E)$ and $f_A(E)$ are independent of the detector arrangement. The influence of the detector configuration on the component $f_R(E)$ is essential. This component determines the neutron sensitivity in the neutron energy range from 0.1 MeV to 15 MeV [5].

2. SOME REMARKS ON THE CALCULATION OF THE NEUTRON SENSITIVITY COMPONENT

The calculation of the component $f_R(E)$ was carried out for a detector-radiator combination which is shown schematically in fig.1. The luminophor is embedded in a mixed radiator which consists of polyethylene, and this detector element is covered by a polyethylene (PE) contact radiator. The luminescent material is $CaF_2:Mn$.

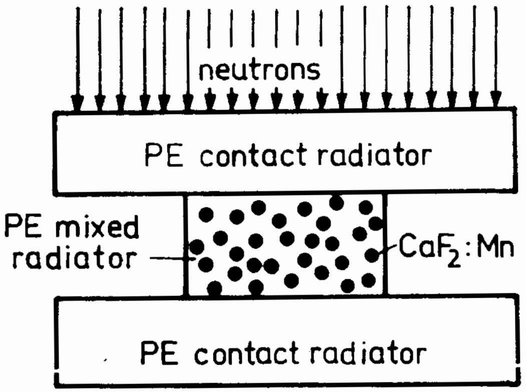

Fig.1. Detector-radiator combition (schematic).

The calculations are simplified by using the following assumptions:

1. A homogeneous,ordered distribution of the luminophor in the mixed radiator is supposed.

2. The luminophor grains are spheres with a unit mean diameter.

3. The $CaF_2:Mn$ grains are placed space-centred in cubic cells.

4. Only first collision effects are considered.

5. The luminophor grains are excited only by protons. Other heavy charged particles which are also produced in the radiator material, for instance alphas and carbon recoils, are not considered.

The developed Monte-Carlo programme MIXRAD/83 [6] has the aim to calculate firstly the absorbed energy by passing of recoil protons across the luminescent material and secondly the part of the absorbed proton energy which is emitted as OSL light during the evaluation process. A Monte-Carlo calculation of the neutron histories is disadvantageous, because for the investigated detectors of thicknesses between 300 μm and 1 mm only about 1 of 100 neutrons interacts in the radiator volume Therefore the calculation of the in fact produced protons was carried out. The mean effective energy of OSL per primary neutron E_n^{OSL} was calculated on the base of the relationship

$$E_n^{OSL} = P_{el} \cdot E_p^{OSL} , \qquad (4)$$

where P_{el} is the probability of the neutron-proton interaction in the investigated radiator field and E_p^{OSL} is the mean value of the absorbed proton energy which is emitted as OSL light. By considering only first collision effects the quantity P_{el} is given by

$$P_{el} = \frac{m_{rad} \cdot K_{st} \cdot N_A}{M_r} \sigma(E) \qquad (5)$$

with m_{rad} as the radiator mass, K_{st} as the stoichiometric coefficient of hydrogen in the chemical compound polyethylene, N_A as the Loschmidt constant, M_r as the molar mass of PE,and $\sigma(E)$ as the interaction cross section for the elastic neutron-proton scattering of neutrons with energy E. By calculating the radiator mass only the part of the contact radiator is considered from which produced protons reach the sensitive space cells of the detector element. The equipartition of the reaction rate in the whole radiator is obtained by alloting x-, y- and z-coordinates. Coordinates which are placed in luminophor grains are not considered. By alloting the cosine of the scattering angle of the protons in the laboratory system θ the proton energy E_p is given according to the expression

$$E_p = E \cdot \cos^2\theta \qquad (6)$$

with E as the energy of the primary neutrons. The distribution functions of $\cos\theta$ and of the azimuthal angle are given by the laws of the elastic scattering between neutrons and protons. Altogether after these calculation steps the origin place, the proton energy and the flying direction of the protons in the radiator and luminescent material are determined well defined. The slowing down of the protons in the different materials is calculated with the aid of the computer programme STOPOW [7]. Results of the experimental determination of stopping power values are compiled in [8].

By passing of a luminophor grain the absorbed energy ΔE in the luminescent material is calculated according to equation (7)

$$\Delta E = E_{p1} - E_{p2} , \qquad (7)$$

where E_{p1} is the incident proton energy and E_{p2} is the exit proton energy, respectively.

The OSL effective proton energy E_p^{OSL} is obtained by multiplication of the energy difference ΔE with the so-called mean relative light conversion factor $\bar{\eta}_{\Delta E}$ for the investigated energy difference [8,9,10]

$$E_p^{OSL} = \Delta E \cdot \bar{\eta}_{\Delta E} . \qquad (8)$$

But such relative light conversion factors for CaF_2 :Mn are not available completely at present. For that reason mean relative light conversion factors based on the LET conception were used [9,11]. The determination of the LET is shown in fig.2 schematically. The mean relative light conversion factors for protons were taken from [9]. The results of these calculation steps is the expected value of the OSL effective proton energy and its mean standard derivation. The mean received dose per incident neutron δ is then given by formula (9)

$$\delta = E_n^{OSL} / m_1, \qquad (9)$$

m_1 is the luminophor mass of the detector.

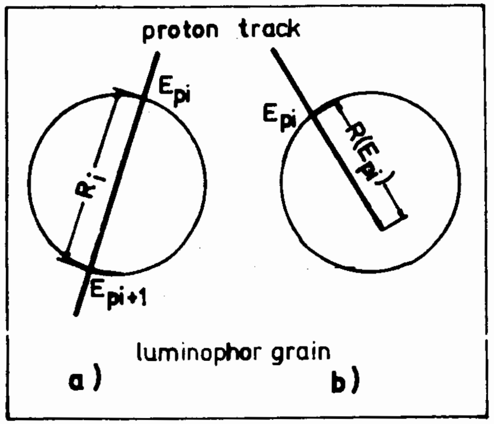

Fig. 2. Determination for LET in calculation.

The neutron sensitivity component $f_R(E)$ is accordingly a function of several parameters. Especially interesting for an optimization of the detector arrangement is the influence of different detector parameters on the component $f_R(E)$. These detector parameters are the detector thickness, the thickness of the contact radiator, the phosphor content of the detector element, the relative light conversion factor of the used luminescent material and the phosphor grain size.

3. SOME RESULTS OF THE SYSTEMATIC INVESTIGATIONS

For a given luminophor the relative light conversion factor is a characteristic dosimetric property. In [9,12] it was shown that for CaF_2 :Mn the mean relative conversion factor is less than 1. By using other phosphors, for instance BeO , an increase of the component $f_R(E)$ is possible, because relative light conversion factors greater 1 could be expected [13].

The influence of the other above-mentioned parameters on the sensitivity part $f_R(E)$ was investigated for different detectors experimentally and theoretically. The experimental determination of the neutron sensitivity was carried out at three different neutron sources:

1. (d,D) generator of the Dresden University of Technology with a neutron energy of 3.2 MeV.
2. Cyclotron U-120 of ZfK Rossendorf. The mean energy of the fast neutrons is 5.7 MeV.
3. (d,T) generator of the Dresden University of Technology with a neutron energy of 14.7 MeV.

By using a two-detector-method and an individual calibration of the detectors the maximum error in experimental determination amounts to 21%, about 12% of which results from the error of the neutron fluence determination.

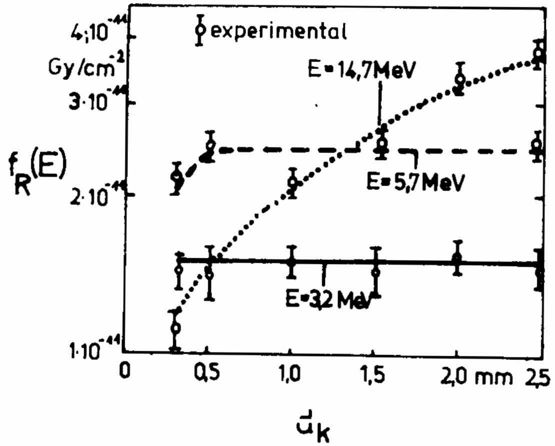

Fig. 3. Dependency of the sensitivity component $f_R(E)$ on the contact radiator thickness d_K

Figure 3 shows the dependence of the sensitivity component $f_R(E)$ on the contact radiator thickness d_K. The obtained results have confirmed the results which were obtained for planar TL detector radiator combinations [14]: The highest neutron sensitivity is obtained if the range of the protons with the maximum energy is less than the contact radiator thickness. Therefore the following investigations were carried out with a contact radiator of 2.5 mm thickness.

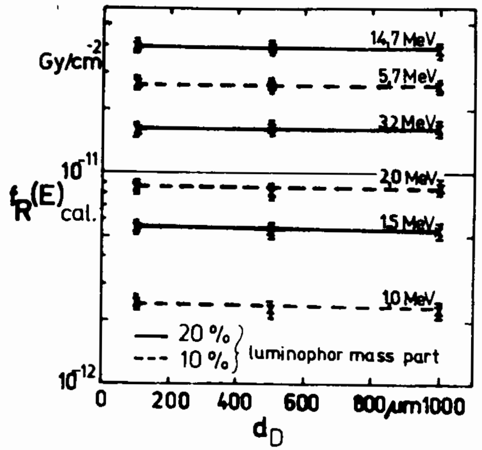

Fig. 4. $f_R(R)$ as a function of the detector thickness d_D for different neutron energies and luminophore contains.

An essential influence of $f_R(E)$ can have the detector thickness d_D. On this aspect different OSL detectors which contain 20 and 30 mass percent luminescent material were investigated, respectively. The calculated results are presented in fig.4 as function of the neutron energy. The neutron sensitivity component decreases with increased detector thickness insignificantly. For high neutron energies the protons, which are produced in the contact radiator, determine the sensitivity. But only the higher space cells of the sensitive layer contribute to the neutron sensitivity effectively. For smaller neutron energies protons, which are produced in the mixed radiator are important. But this part is independent of the detector thickness, because only first collision effects are considered.

For checking the general validity of the calculated results measurements of the neutron sensitivity were carried out. The obtained results for different OSL detector radiator arrangements are given in tab.1. It can be seen that there is a good agreement between theoretically and experimentally determined values. The experimental neutron sensitivity components are mean values of 20 detectors.

Table 1

Calculated and experimental neutron sensitivity components $f_R(E)$ for OSL detectors by variation of the detector thickness (other detector parameters: grain size = 20 µm, luminophor mass part = 30%)

neutron energy in MeV	detector thickness in µm	$f_R(E)_{cal}$ in 10^{-11} Gy/cm^{-2}	$f_R(E)_{exp}$ in 10^{-11} Gy/cm^{-2}
14,7	1000	3,67	3,75 ± 0,39
	500	3,78	3,83 ± 0,45
	100	3,92	3,80 ± 0,43
5,7	1000	2,31	2,45 ± 0,40
	500	2,28	2,40 ± 0,34
	100	2,51	2,46 ± 0,37
3,2	1000	1,42	1,61 ± 0,30
	500	1,43	1,65 ± 0,37
	100	1,54	1,62 ± 0,27

The luminophor mass part influences the dosimetric properties of luminescent detectors [15,16]. The investigation results for OSL detectors which contain different luminophor contents are compiled in tab.2. The quantity in brackets describes the luminophor content. The agreement between calculated and ex-

Table 2

Calculated and experimental neutron sensitivity components $f_R(E)$ for different neutron energies by variation of the luminophor mass part of CaF_2:Mn-PE-OSL detectors

E in MeV	detector	$f_R(E)_{cal}$ in 10^{-11} Gy/cm^{-2}	$f_R(E)_{exp}$ in 10^{-11} Gy/cm^{-2}
14,7	CaF_2:Mn-PE (10)*	3,85	3,78 ∓ 0,47
	CaF_2:Mn-PE (20)	3,76	3,69 ± 0,44
	CaF_2:Mn-PE (30)	3,56	3,61 ± 0,42
5,7	CaF_2:Mn-PE (10)	2,43	2,55 ± 0,33
	CaF_2:Mn-PE (20)	2,27	2,39 ± 0,36
	CaF_2:Mn-PE (30)	2,18	2,30 ± 0,30
3,2	CaF_2:Mn-PE (10)	1,39	1,46 ± 0,23
	CaF_2:Mn-PE (20)	1,26	1,22 ± 0,23
	CaF_2:Mn-PE (30)	1,25	1,28 ± 0,22

* Detectors of thickness of 1000 µm and a luminophor grain size of 35 µm were investigated. The values in brackets describe the luminophor mass part of the detectors.

perimentally determined values is also good. These results show, that the use of detectors with a small luminophor content is favourable. The detector which contains 10% CaF_2:Mn has the highest neutron sensitivity. But the differences to the other investigated detectors are no more than about 10%.

The use of luminophors with different grain sizes has effects to the dosimetric properties of TL detectors. FACEY et al. [17] have shown that an embedding of fine-grained $CaSO_4$:Dy TL matrial in silicon rubber raises the neutron sensitivity. This effect is dependent on the neutron energy. Particularly at lower energies the improvement of the component $f_R(E)$ is important. The relative improvement is little or none at 14 MeV, where the proton range greatly exceeds the diameter of even the largest luminophor particles. For that reason OSL detectors with a thickness of 500 µm and a luminophor content of 20% were investigated by variation of the luminophor grain sizes. The results are represented in fig.5. As would be expected, the influence of the different grain sizes on the neutron sensitivity component $f_R(E)$ is insignificant in the energy range from 7 to 15 MeV. The relative differences are no more than 8%. For neutron energies below 7 MeV the neutron sensitivity increases by using very fine-grained CaF_2:Mn.

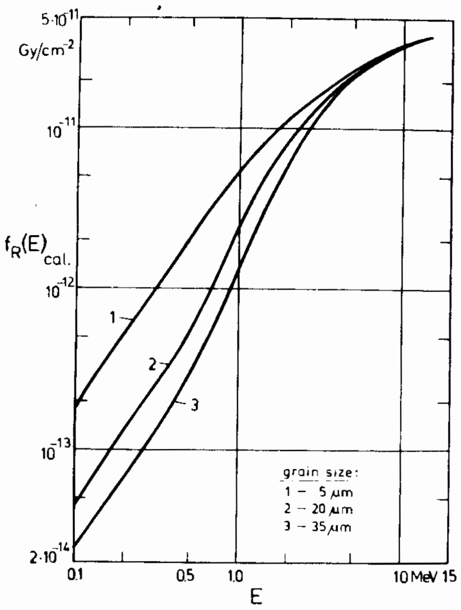

Fig. 5. The influence of different grain sizes on the neutron sensitivity component $f_R(E)$.

Detectors based on coarse-grained CaF_2 phosphor are markedly less sensitive than fine-grained luminescent materials in the lower energy range.

Moreover the neutron sensitivity was determined for different grain sizes experimentally. A comparison of calculated and experimental results is given in tab.3. The errors for the experimental neutron sensitivities amount to about 10 to 21%. The fractional standard derivation of the calculations is less than 3.5%. The highest neutron sensitivity is obtained for detectors with a grain size of 5 μm.

Table 3

Influence of the luminophor grain size on the calculated and experimentally determined sensitivity components $f_R(E)$ (used detectors: thickness = 500 μm, luminophor mass part = 20%)

E in MeV	grain size in μm	$f_R(E)_{cal}$ in 10^{-11} Gy/cm^{-2}	$f_R(E)_{exp}$
14,7	5	3,74	3,86 ± 0,40
	15	3,82	3,79 ± 0,45
	20	3,87	3,91 ± 0,41
	35	3,73	3,82 ± 0,46
5,7	5	2,48	2,59 ± 0,35
	15	2,39	2,45 ± 0,36
	20	2,33	2,39 ± 0,50
	35	2,25	2,30 ± 0,32
[illegible]	5	1,68	1,67 ∓ 0,28
	15	1,54	1,60 ± 0,29
	[illegible]	1,50	1,48 ± 0,26
	35	1,31	1,[illegible] ± [illegible],26

4. FINAL REMARKS

Finally the results of the systematic investigations of the influence of different detector parameters on the neutron sensitivity component $f_R(E)$ of OSL detectors will be summarized once more:

1. The detector thickness, the luminophor content, the phosphor grain size as well as the contact radiator thickness influence the absolute values of the neutron sensitivity component.
2. By using a contact radiator of 2,5 mm PE the highest neutron sensitivities were obtained for all neutron energies in the range from 0.1 to 15 MeV.
3. The influence of the detector thickness on $f_R(E)$ is little or none for the investigated detector thicknesses.
4. The phosphor content of the OSL detectors has an effect to the component $f_R(E)$. The best results were obtained for detectors with a small luminophor content.
5. An important influence on $f_R(E)$ has the used luminophor grain sizes. Detectors based on very fine-grained luminescent material have the highest neutron sensitivity for fast neutrons.

REFERENCES

1. J.Henniger et al. Nucl.Instr.& Meth. 1982, 204, p.209.
2. J.Fellinger, J.Henniger, K.Hübner. TU-Information 05-14-81, Dresden, 1981.
3. R.Bernhardt, L.Herforth. Proc. 4th Intern.Conf.on Luminescence Dosimetry, Krakow 1974, vol.III, p.1091.
4. J.Henniger, K.Hübner, G.Pretzsch. Nucl.Instr.& Meth.,1982, 192, p.453.
5. J.Fellinger, K.Hübner, J.Henniger. Kernenergie, 1981, 24, p.292.
6. Computer Program MIXRAD/83, JINR version 1983 by J.Henniger, unpublished.
7. J.Henniger, B.Horlbeck. JINR, 10-83-366, Dubna, 1983.
8. J.Henniger, K.Hübner. TU-Information 05-03-82, Dresden, 1982.
9. K.Hübner, J.Henniger. TU-Information 05-18-80, Dresden, 1980.
10. P.M.Rinard, G.G.Simons. Nucl.Instr.Meth., 1979,158,p.54[illegible].
11. B.Jähnert. Proc. Third Intern.Conf. on Luminescence Dosimetry, Risö 1971, part III, p.1031.
12. P.Schmidt et al. TU-Information 05-08-85, Dresden, 1985.
13. K.Becker. Solid State Dosimetry. CRC Press, Ohio 1974.
14. J.Fellinger, J.Henniger, K.Hübner. JINR, E16-83-880, Dubna, 1983.

15. A.S.Pradhan, R.C.Bhatt. Nucl.Instr.Meth.,1979,161(2), p.243.
16. S.H.Li, P.S.Weng. Journ.Nucl.Sci.Techn.,1979,16(7),p.520.
17. R.A.Facey,R.A.Gravelle.Proc.Ann.Meeting of the Health Phys.Soc., Houston 1974.

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Феллингер Ю. и др. E16-85-814
Влияние различных параметров OSL -детекторов на их чувствительность к нейтронам

На основании уже представленного метода для вычисления чувствительности к нейтронам OSL -детекторов с высоким содержанием водорода проведено систематическое исследование влияния на нее различных параметров детектора. Толщины детектора и прилегающего радиатора, содержание и размер зерна используемого люминофора влияют на чувствительность к нейтронам прежде всего в энергетической области быстрых нейтронов. В особенности, использование люминофора с малым зерном значительно увеличивает чувствительность, тогда как другие параметры оказывают на нее малое влияние.

Нейтронные чувствительности, вычисленные и экспериментально определенные при варьировании параметров детектора, находятся в хорошем согласии.

Работа выполнена в Отделе радиационной безопасности и радиационных исследований ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна 1985

Fellinger J. et al. E16-85-814
Influence of Different Detector Parameters on the Neutron Sensitivity of OSL-Detectors

On the base of a method, already represented, for the calculation of the neutron sensitivity of OSL detectors with a high contents of hydrogen a systematic investigation of the influence of different detector parameters on the neutron sensitivity was carried out. The detector thickness, the thickness of the contact radiator, the luminophor contents and the grain size of the used luminophor influence the neutron sensitivity, first of all in the energy range of fast neutrons. Especially the use of small grain luminophor considerably increases the sensitivity whereas the other parameters have a small influence on the neutron sensitivity.

The neutron sensitivities calculated and experimentally determined at variation of the detector parameters are in good agreement.

Communication of the Joint Institute for Nuclear Research. Dubna 1985