Development of a $CaSO_4$:Dy TL Detector for Thermal Neutron Measurement

Jeong Seon Yang*, Jung-Il Lee, Jang Lyul Kim, Bong-Hwan Kim
Korea Atomic Energy research Institute Yuseong P. O. Box 105, Daejeon, Korea

1. Introduction

$CaSO_4$:Dy thermoluminescence dosimeter (TLD) has been widely used as a personal or environmental dosimeter because of its high sensitivity to radiation. But $CaSO_4$:Dy TL material cannot be applied to neutron dosimeter in spite of its good TL characteristics because the neutron capture cross section of the constituents of $CaSO_4$:Dy are small and then the interaction between the thermal neutron and the phosphor is minimal. One method to enhance the neutron interaction is obtained by introducing an element of ^{6}Li into the TL powder because ^{6}Li has a large thermal neutron capture cross section and acts as a neutron absorption centre.

Several studies for a thermal neutron dosimetry using $CaSO_4$:Dy TLD have been performed so far[(1-4)]. Most of the neutron dosimetry results reported in the literature have been obtained by using powder type $CaSO_4$:Dy TL dosimeters rather than pellet type dosimeters[1,4)].

In KAERI(Korea Atomic Energy Research Institute), studies on the development of a high sensitivity TL pellet for a gamma and beta dose measurement(KCT-300) using $CaSO_4$:Dy TL material have been conducted[5)]. Based on development of KCT-300, this study developed the TL pellet for a neutron dosimetry by embedding a ^{6}Li-compound into $CaSO_4$:Dy TL phosphor. In the KCT-306 TL pellets, the α particle and ^{3}H particle are produced via the $^6Li(n,\alpha)^3H$ reaction when exposed to a thermal neutron, and their energies are absorbed by the $CaSO_4$:Dy TL phosphor to produce a TL.

2. Experiments and Results

2.1 Fabrication of KCT-306

The $CaSO_4$:Dy TL phosphors were prepared at KAERI following the method of Yamashita et al[6)]. The dosimeter proposed here uses a mixture of $CaSO_4$:Dy powder, binding material $NH_4H_2PO_4$ powder and non-luminous $^6Li_2CO_3$ powder (neutron target material). In the mixture of $CaSO_4$:Dy + $^6Li_2CO_3$ + $NH_4H_2PO_4$, the $^6Li_2CO_3$ compound chemically reacts with an excessive amount of $NH_4H_2PO_4$. As the result of the chemical reaction, the total amount of the $^6Li_2CO_3$ compound is changed to $^6Li_3PO_4$ compounds and the remnant of $NH_4H_2PO_4$ is changed to P-compounds.

KCT-306 has been obtained after the cold pressing of a homogeneous mixture of $CaSO_4$:Dy TL phosphor, $NH_4H_2PO_4$ powder as binding material and $^6Li_2CO_3$ powder.

2.2 Optimum Concentration of ^{6}Li-compound and $CaSO_4$:Dy TL Phosphor

To determine the ^{6}Li compound, various ^{6}Li compounds were tested as a thermal neutron target material, and a non-luminous $^6Li_2CO_3$ compound was concluded to be the most useful material from the viewpoints of its mechanical strength and glow curve structure.

Figure 1 shows the TL response for the neutron and gamma of the KCT-306 with the weight ratio of the $CaSO_4$:Dy TL phosphor($^6Li_2CO_3$ compound + $CaSO_4$:Dy TL phosphor =90wt%), and the neutron response to the gamma response ratio (N/ γ ratio) is also shown also in the Fig 1. The TL response for the neutron and gamma of the KCT-306 with respect to that of KCT-306 gradually increase with an increase in the $CaSO_4$:Dy TL phosphors content (decrease in $^6Li_2CO_3$ content). But the neutron N/ γ ratio is decreased rapidly with an increase in the $CaSO_4$:Dy TL phosphors content.

At a result, the optimum $CaSO_4$:Dy TL phosphors and $^6Li_2CO_3$ powder contents are determined as 20wt% and 70wt%.

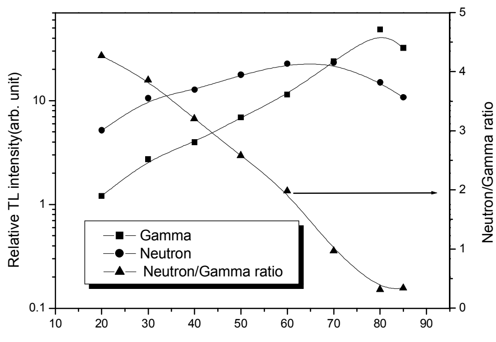

Figure 1. Dependence of main peak intensity of KCT-306 on $^6Li_2CO_3$-compound and $CaSO_4$:Dy TL phosphor concentration

2.3 Optimum Concentration of Binding Material P-Compounds

Before a manufacturing of the embedded ^{6}Li-compounds KCT-306, optimum P-compounds contents must be determined, by considering the neutron and gamma sensitivity. The content of P-compounds means the remnant after a chemical reaction with $^{6}Li_2CO_3$ powder. Experiments to determine the P-compounds as a binding material of KCT-306 have been conducted by varying the $NH_4H_2PO_4$ content in the KCT-306. Figure 2 shows the TL response for the neutron, gamma response and neutron response/gamma response ratio of KCT-306 with the P-compounds content.

With an increase in the P-compounds content, the neutron and gamma intensity are increased by up to 30wt% after which they decrease. But the neutron response/Gamma response ratio is increased by up to 20wt% only. At a result, the optimum P-compounds content is determined as 20wt%.

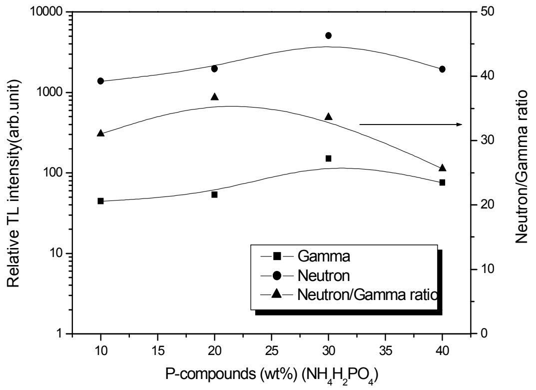

Figure 2. Dependence of main peak intensity of KCT-306 on P-compounds content

2.4 Sensitivity to Gamma and Neutron Radiation

Newly developed TL detectors for a neutron detector (KCT-306 and KCT-300), TLD-600 and TLD-700, TLD-600H and TLD-700H detectors were irradiated in mixed neutron gamma fields of a D_2O moderated (30cm dia.) ^{252}Cf neutron source at KAERI. In these experiments the TLD-700, TLD-700H and KCT-300 were used at the same time as gamma ray discriminators. The KCT-300 dosimeter has a very small neutron cross-section, so it only responds to the gamma in a neutron/gamma mixed field. The gamma irradiation of the TL detectors was carried out using a ^{137}Cs source at KAERI. Both types of the TL detector (enriched by ^{6}Li or only ^{7}Li) have comparable sensitivities for the gamma rays. There may be small differences, in the gamma sensitivity between the ^{6}Li and ^{7}Li detector with the ^{6}Li detectors normally being less sensitive. Therefore, for measuring a gamma exposure, the two detectors should be read separately and the appropriate calibration factor applied for each reading value. The ^{6}Li and ^{7}Li detectors are used in pairs, with the reading of the ^{7}Li TLD (gamma-response only) being subtracted from the ^{6}Li reading (gamma and neutron response). The responses for the neutron from a ^{252}Cf neutron source are shown in Table 1.

Table 1. Relative neutron response of KCT-306 and Harshaw neutron TLD (TLD-600 and TLD- 600H)

	N+r(^{252}Cf)	^{137}Cs	N/r ratio
KCT-306	1.3	1.2	**37.24**
KCT-300	1.22	42.37	
TLD-600	1	1	27.32
TLD-700	0.04	1.13	
TLD-600H	11.32	41.13	8.1
TLD-700H	1.14	37.73	

3. Summary and Conclusion

In this study the development of pellet type TL dosimeters for a neutron measurement, designated as KCT-306 has been presented. The TL pellets combination of KCT-306/KCT-300, the commercially available TLD-600/TLD-700, and TLD-600H/TLD-700H have been irradiated in the neutron/gamma mixed fields of a D_2O moderated(30cm dia.) ^{252}Cf neutron source at KAERI.

The TLD-700, TLD-700H and KCT-300 were used at the same time as gamma ray discriminators in the mixed fields. It was found that the neutron/gamma response ratio of KCT-306/KCT-300, which is developed in this study, was about 4 times higher than that of the commercial TLD-600/TLD-700 or TLD-600H/TLD-700H. This means that the KCT-306 in combination with KCT-300 could be used as a thermal neutron dosimeter in a mixed radiation field.

REFERENCES

1) Mayhugh, M. R., Watanabe, S. and Muccillo, R. Proc. Third Int. Conf. Lum. Dosimetry, Riso, Denmark, 1971, 3: 1040

2) Morgan, M. D., Lacombe, M. A. and Stoebe, T. G. Development of a thermal neutron dosemeter utilizing the $CaSO_4$:Dy system. Radiat. Prot. Dosim., 1984, 6: 321-324

3) IGA,K., Yamashita, T., Takenaga, M., Yasuno, Y., Oonishi, H. and Ikedo, M., Composite TLD Based on $CaSO_4$:Tm for γ-rays, X-rays, β-rays and thermal neutron, Health physics Pergamon Press, 1977, 33: 605-610

4) Beach, J. L. and Huang, C. Y., Mixed Field Dosimetry with $CaSO_4$(Tm)Li, Health physics Pergamon Press, 1976, 31: 452-455

5) Yang Jeong- Seon et al., Development of phosphorus-compound $CaSO_4$:Dy(KCT-300) TL pellet ,J. the Korean nuclear society, 2002, 34: 142-145

6) Yamashita, T., Nada N., Onishi, H. and Kitamura, S., Calcium sulfate activated by thulium or dysprosium for thermoluminescence dosimetry, Health Phys., 1971, 21: 295