Development of a CaSO$_4$:Dy TL Detector for Thermal Neutron Measurement

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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-306) 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 $\alpha$ particle and $^3$H particle are produced via the $^6$Li($n$,n')$^7$H 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$_4$H$_2$PO$_4$ powder and non-luminous $^6$Li$_2$CO$_3$ powder (neutron target material). In the mixture of CaSO$_4$:Dy + $^6$Li$_2$CO$_3$ + NH$_4$H$_2$PO$_4$, the $^6$Li$_2$CO$_3$ compound chemically reacts with an excessive amount of NH$_4$H$_2$PO$_4$. As the result of the chemical reaction, the total amount of the $^6$Li$_2$CO$_3$ compound is changed to $^6$LiPO$_4$ compounds and the remnant of NH$_4$H$_2$PO$_4$ 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$_4$H$_2$PO$_4$ powder as binding material and $^6$Li$_2$CO$_3$ 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 $^6$Li$_2$CO$_3$ 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($^6$Li$_2$CO$_3$ compound + CaSO$_4$:Dy TL phosphor =90wt%), and the neutron response to the gamma response ratio (N/\gamma ratio) is also shown 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 (increase in $^6$Li$_2$CO$_3$ content). But the neutron N/\gamma 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 $^6$Li$_2$CO$_3$ powder contents are determined as 20wt% and 70wt%.

![Figure 1. Dependence of main peak intensity of KCT-306 on $^6$Li$_2$CO$_3$-compound and CaSO$_4$:Dy TL phosphor concentration](image_url)

2.3 Optimum Concentration of Binding Material P-Compounds

Before a manufacturing of the embedded $^6$Li-compounds KCT-306, optimum P-compounds contents

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must be determined, by considering the neutron and gamma sensitivity. The content of P-compounds means the remnant after a chemical reaction with $^4\text{Li}_2\text{CO}_3$ powder. Experiments to determine the P-compounds as a binding material of KCT-306 have been conducted by varying the NH$_4$H$_2$PO$_4$ 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](image)

### 2.4 Sensitivity to Gamma and Neutron Radiation

Newly developed TL detectors for a neutron detector (KCT-306 and KCT-300), TL-600 and TL-700, TL-600H and TL-700H detectors were irradiated in mixed neutron gamma fields of a D$_2$O moderated (30cm dia.) $^{252}$Cf neutron source at KAERI. In these experiments the TL-700, TL-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 $^6\text{Li}$ or only $^7\text{Li}$) have comparable sensitivities for the gamma rays. There may be small differences, in the gamma sensitivity between the $^6\text{Li}$ and $^7\text{Li}$ detector with the $^7\text{Li}$ 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 $^6\text{Li}$ and $^7\text{Li}$ detectors are used in pairs, with the reading of the $^7\text{Li}$ TLD (gamma-response only) being subtracted from the $^6\text{Li}$ 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 (TL-600 and TL-600H)](image)

### 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 TL-600/TL-700, and TL-600H/TL-700H have been used in the neutron/gamma mixed fields of a D$_2$O moderated (30cm dia.) $^{252}$Cf neutron source at KAERI.

The TL-700, TL-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 TL-600/TL-700 or TL-600H/TL-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


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