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■ 論 文 ■

Thermoluminescent Response of Thin LiF:Mg,Cu,Na,Si Detectors to Beta Radiation

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얇은 LiF:Mg,Cu,Na,Si 검출기의 베타선장에 대한 TL 반응

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Abstract - Thermoluminescent (TL) response characteristics of a thin LiF:Mg,Cu,Na,Si Teflon detectors have been studied for use in beta radiation detection. The detectors were fabricated from a mixture of LiF:Mg,Cu,Na,Si phosphor and Teflon powder which was molded into a thin disk form of 50 ㎎/㎝^{2} thickness. These detectors were irradiated to beta fields of ^{147}Pm, ^{204}Tl and ^{90}Sr/^{90}Y sources with a covering of Kapton foil (2 ㎎/㎝^{2}) and photon irradiation was carried out with a ^{137}Cs source at the Korea Atomic Energy Research Institute (KAERI). Batch uniformity was estimated to be 4.7% and the beta dose response presented linear relationship from 0.1 mGy to 100 Gy. The beta energy responses of thin detectors normalized to ^{137}Cs were presented as 0.46, 1.09 and 1.06 for ^{147}Pm, ^{204}Tl and ^{90}Sr/^{90}Y beta rays, respectively. The evaluated values for angular responses were 0.93 ± 0.03 (^{147}Pm), 0.94 ± 0.04 (^{204}Tl), and 0.92 ± 0.05 (^{90}Sr/^{90}Y). The results satisfied well a proposed ISO Standard for beta ray dosimeters.

Key Words: thermoluminescent, LiF:Mg,Cu,Na,Si, detector, beta radiation, dosimetry

요약 - 최근 개발된 감도가 좋은 LiF:Mg,Cu,Na,Si TL물질을 Teflon과 혼합한 후, 얇은 디스크 형태로 압축 · 성형한 얇은 LiF:Mg,Cu,Na,Si Teflon 검출기를 제작하고 베타선 검출기로서의 TL 반응특성을 연구하였다. 한국원자력연구소의 ^{147}Pm, ^{204}Tl 및 ^{90}Sr/^{90}Y 베타선원을 이용하여 두께 2 ㎎/㎝^{2}인 Kapton 박막을 덮은 상태로 베타선을 조사하였다. 제작한 얇은 LiF:Mg,Cu,Na,Si 검출기들의 ^{137}Cs에 대한 batch 균질성은 4.7%, 베타선에 대한 선량의존성은 0.1 mGy에서 100 Gy까지 선형성을 나타내고, 에너지의존성은 ^{147}Pm, ^{204}Tl 및 ^{90}Sr/^{90}Y 베타선에 대해 각각 0.46, 1.09 및 1.06 이었다. 그리고 베타선에 대한 방향의존성은 0.93 ± 0.03 (^{147}Pm), 0.94 ± 0.04 (^{204}Tl) 및 0.92 ± 0.05 (^{90}Sr/^{90}Y)으로, 이들 얇은 LiF:Mg,Cu,Na,Si 검출기들에 대한 TL 반응특성의 결과는 국제표준기구(ISO)의 베타선량계 기준을 잘 만족하였다.

중심어: TL, LiF:Mg,Cu,Na,Si, 검출기, 베타 방사선, 선량측정

INTRODUCTION

Personal detectors for beta radiation should be designed to measure personal dose equivalent $H_p(d)$ at a depth of 7 ㎎/㎠ for skin. For beta energies below 1 MeV, the response significantly changes the energy distribution dependent upon the thickness of detectors. For the dose measurement of weakly penetrating radiation, ideally the skin dose should be measured with a tissue-equivalent detectors at 7 ㎎/㎠ depth. Thicker detectors usually have the lower sensitivities to low energy beta radiation. For this reason, TL detectors of thin thickness are the most widely used for the measurement particularly in personal extremity dosimetry. Several methods of producing an effectively thin TL detector have been tested, such as boron surface diffusion to create a new high temperature trap in LiF[1] or carbon loading of LiF-based material[2]. However, there have been problems of low TL responses in using these thin TL detectors. A different detector type makes use of a LiF:Mg,Cu,P layer of 0.03 ㎜ thickness, sintered to an inactive 0.7 ㎜ thick base[3]. Because of the inactive base, the thin detector is mechanically stable and its photon energy response is similar to that of a thick detector.

Recently developed LiF:Mg,Cu,Na,Si phosphor[4] has a high sensitivity and a flat energy response for photons due to its tissue equivalence. In the present work, thin LiF:Mg,Cu,Na,Si TL detectors were fabricated by using the LiF:Mg,Cu,Na,Si phosphor and their TL characteristics for beta radiation detection were investigated. The results were compared with a proposed ISO standard for beta ray dosimeters[5].

MATERIALS AND METHODS

Thin LiF:Mg,Cu,Na,Si Teflon TL detectors were fabricated from a mixture of LiF:Mg,Cu,Na,Si phosphor and Teflon powder as an adhesive material at the liquid nitrogen temperature. The mixture was molded into a thin disk (4.5 ㎜ in diameter) by pressing at room temperature. The response of the detectors to photon was studied[6] but their thickness was too thick to measure beta radiation. Thus for the detection of beta radiation, we have fabricated LiF:Mg,Cu,Na,Si Teflon detectors into thin disk form of 50 ㎎/㎠ (physically 0.2 ㎜) thickness.

The irradiation of samples was carried out using the Physikalisch Technische Bundesanstalt (PTB) Beta Secondary Standard System at KAERI, with ^{147}Pm, ^{204}Tl and ^{90}Sr/^{90}Y sources. The detectors were always placed on a 5 ㎝ thick PMMA phantom and covered with a 2 ㎎/㎠ Kapton foil during the irradiation. Because the relative beta ray response is nearly energy independent for protective cover 2 ㎎/㎠ thick[7]. Photon irradiation was carried out by a ^{137}Cs source and samples were exposed between two 2 ㎜ thick PMMA plates, to assure charged particle equilibrium.

For measurements of the beta energy response, four groups of detectors were irradiated with beta rays from ^{147}Pm, ^{204}Tl and ^{90}Sr/^{90}Y sources and by ^{137}Cs photons to doses of about 10 mGy. The beta dose response was investigated with ^{90}Sr/^{90}Y sources in the range of 1 μGy to 100 Gy. The angular dependence of the TL response was obtained for ^{147}Pm, ^{204}Tl and ^{90}Sr/^{90}Y sources at angles of 0°, 15°, 30°, 45° and 60°. A 0° incidence angle means normal incidence. Data points of TL response were estimated by the average of ten experimental data.

All TL responses of samples were measured with a TLD reader (Teledyne, System 310) at a constant nitrogen flux. Measurements were made 24 hours after irradiation to eliminate the influence of low temperature TL glow peaks. The TL intensity is taken from the total glow curve area at a linear heating rate of 5 ℃$\cdot$s^{-1}.

RESULTS AND DISCUSSION

The batch uniformity is variation in sensitivity within a batch, which is defined as % standard deviation (1σ in %) in the TL response of detectors. Figure 1 shows the distribution of the TL response of detectors within a batch. For the seven hundred detectors, the batch uniformity was estimated to be 4.7 %.

The detection limits of the developed detectors were evaluated as a detection threshold equal to 3σ of the background for unirradiated detectors. The groups of ten detectors were prepared and the zero-dose was read out. Then the detection threshold was calculated to be 14.4 μGy.

Beta dose response is shown in Figure 2. The detectors irradiated with the ^{90}Sr/^{90}Y source presented a linear response from 0.1 mGy to 100 Gy without supralinearity or saturation.

The energy dependence is shown in Figure 3. The TL response of the thin detectors was measured for ^{147}Pm, ^{204}Tl and ^{90}Sr/^{90}Y beta sources normalized to ^{137}Cs radiation. It can be seen that the beta ray responses normalized to ^{137}Cs were presented as 0.46, 1.09 and 1.06 for ^{147}Pm, ^{204}Tl and ^{90}Sr/^{90}Y beta rays, respectively.

In Figure 4, the angular dependence of TL responses normalized to 137Cs at 0o degree was presented for 137Cs, 147Pm, 204Tl and 90Sr/90Y radiation fields. The TL responses relative to 137Cs at 0o degree over five angles of incidence for 147Pm, 204Tl and 90Sr/90Y

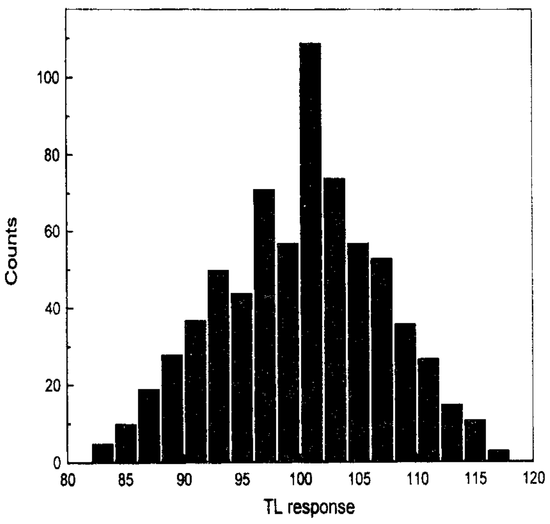

Fig. 1. Batch uniformity: frequency distribution of TL response within a batch.

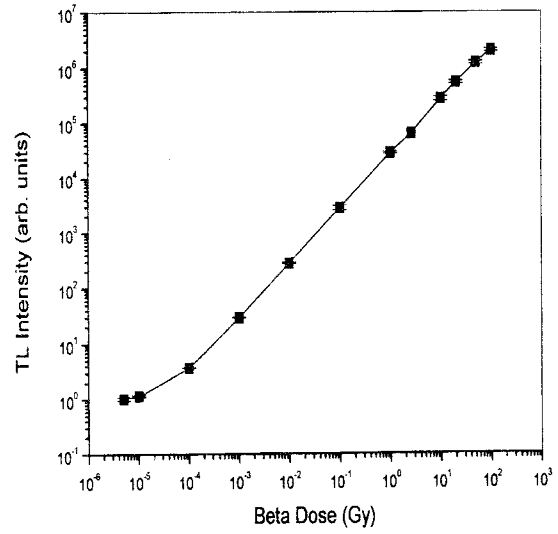

Fig. 2. Dose response as a function of absorbed dose for $^{90}Sr/^{90}Y$ radiation field.

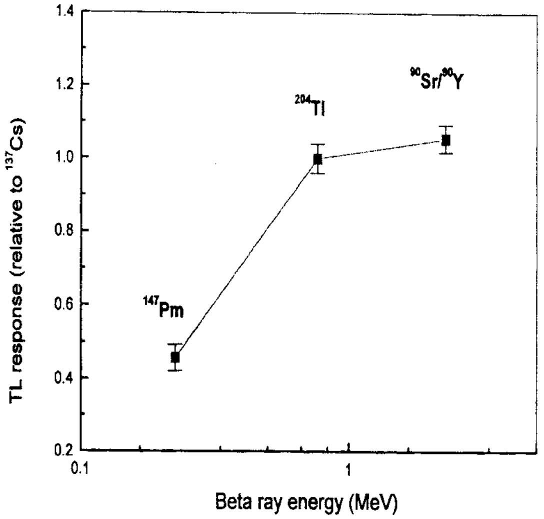

Fig. 3. Beta energy response of thin LiF:Mg,Cu,Na,Si detectors relative to ^{137}Cs.

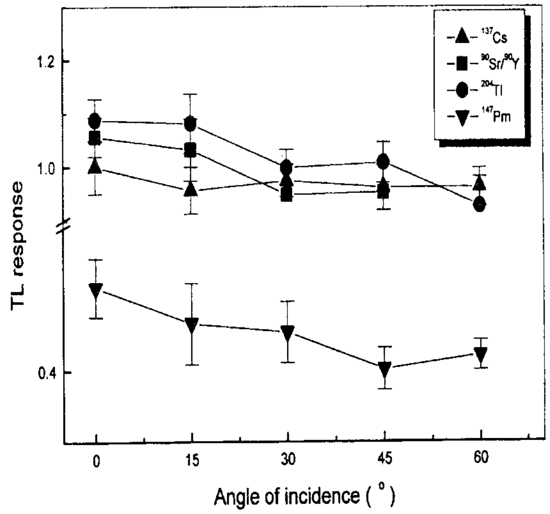

Fig. 4. Angular response of thin LiF:Mg,Cu,Na,Si detectors was compared with the TL response of ^{137}Cs.

beta rays vary from 0.40~0.46, 0.93~1.09 and 0.89~1.06, respectively. The value for 137Cs is 0.97±0.02 which had a smaller angular dependence than those of the beta rays.

An ISO standard[5] formulates the following requirement for dosimeters exposed to beta rays with maximum energies above 0.5 MeV:

$$0.85 < \frac{\sum_{i} M_i}{4M_1} \pm I < 1.15, \qquad (1)$$

where M_i is the detector response at angle $i \in [0°, 20°, 40°, 60°]$, and I is the average uncertainty. In other words, the detector response averaged over four angles of incidence

Table 1. Values of relative beta/^{137}Cs response ratios for thin LiF:Mg,Cu,Na,Si averaged over five incident radiation angles for ^{147}Pm, ^{204}Tl and ^{90}Sr/^{90}Y beta rays.

Relative beta/^{137}Cs response ratios	^{147}Pm	^{204}Tl	^{90}Sr/^{90}Y
$\mathbf{M_1}$	0.46±0.04	1.09±0.04	1.06±0.04
$\sum_i M_i/5$	0.43±0.02	1.02±0.07	0.98±0.07
$\mathbf{I}$	0.03	0.04	0.05
$\frac{\sum_i M_i}{5\,M_1} \pm \mathbf{I}$	0.94±0.03	0.94±0.04	0.92±0.05

Table 2. Comparison of performance requirements for beta ray dosimeters (ISO Standard) and results of thin LiF:Mg,Cu,Na,Si TL detectors.

Characteristics	Range of beta energy (E_{max})	Performance Requirements[5]	Results of thin LiF:Mg,Cu,Na,Si TL detectors
Batch uniformity	All	Coefficient of variation of evaluated values for n dosimeters ≤ 15%	4.7% for 10 mGy
Detection threshold	All	≤ 1 mGy	14.4 μ Gy
Dose response	All	Response ≤ 10% over the range: 1 mGy - 1 Gy	0.1 mGy - 100 Gy
Energy response	0.5 - 3.0 MeV	Response ≤ ±50%	1.09 (^{204}Tl), 1.06 (^{90}Sr/^{90}Y)
Angular response	0.5 - 3.0 MeV	$0.85 < \frac{\sum_i M_i}{4\,M_1} \pm I < 1.15$ At angle i ∈ [0°, 20°, 40° 60°]	0.94±0.04 (^{204}Tl), 0.92±0.05 (^{90}Sr/^{90}Y)

taken together with average measurement uncertainties should not differ by more than 15% with respect to that at normal incidence. Values calculated over five angles of incidence according to condition (1) are shown in table 1. The above condition for angular response is well fulfilled. Thin LiF:Mg,Cu,P detectors (made by INP, Krakow) covered with a 2 ㎎/㎠ foil show that a ^{90}Sr/^{90}Y beta ray response for angles of incidence up to 60° varies between 0.9 and 1.16[7]. And thin layer TLD-700 glued to inactive LiF (developed by Solon Technologies Instruments) varies in angular response from 0.64 to 0.95[8]. It can be seen that these results with thin LiF:Mg,Cu,Na,Si TL detectors indicate good angular characteristics compared to studies of other thin detectors.

A performance criteria for beta ray dosimeters is given in table 2 with our results for comparison. As a whole the results of our thin

LiF:Mg,Cu,Na,Si TL detectors satisfies well the performance criteria. Therefore these thin detectors can be used as a beta detector in a known radiation field, and it may be applied for the low energy beta fields by the proper corrections.

CONCLUSIONS

New thin LiF:Mg,Cu,Na,Si Teflon detectors have been developed using the highly sensitive LiF:Mg,Cu,Na,Si phosphors. The response characteristics of these thin detectors covered by 2 ㎎/㎠ Kapton foil to beta radiation fields have been investigated.

Within a batch of fabricated detectors, batch uniformity was estimated to be 4.7%, the beta dose response presented linear relationship from 0.1 mGy to 100 Gy without supralinearity or saturation. The beta ray responses of thin detectors normalized to ^{137}Cs were presented 0.46, 1.09 and 1.06 for ^{147}Pm, ^{204}Tl and ^{90}Sr/^{90}Y beta rays, respectively. The evaluated values for angular responses were 0.93±0.03 (^{147}Pm), 0.94 ±0.04 (^{204}Tl) and 0.92±0.05 (^{90}Sr/^{90}Y). These results of our thin LiF:Mg,Cu,Na,Si TL detectors were well satisfied the performance criteria. It seems to be encouraging enough to promote the practical application of our thin LiF:Mg,Cu,Na,Si TL detectors in routine extremity monitoring for beta radiation.

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