The Effect of Thin Teflon on TLD Response for *in vivo* Dosimetry of Radiotherapy

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The purpose of this study was to evaluate the performance of the teflon encapsulated TLD rod, which may be used in nuclear medicine for the direct *in vivo* measurements of radiation dose. We analyzed the influence of teflon encapsulation for measuring absorbed dose. An experiment was carried out to evaluate and observe the response of a LiF TLD-100 rod in a thin-wall teflon capsule at different depths in a solid phantom. An adult anthropomorphic phantom was used to measure the absorbed dose using thin teflon encapsulated TLD. The measurements of PDD-, and TMR in solid phantom and athe bsorbed dose in humanoid phantom performed with normal TLD were compared with values obtained by teflon encapsulated TLD. It was demonstrated that the difference of TL response of LiF in phantom with and without teflon thin-wall capsule was less than 3% under the same conditions beyond the build-up region. However, significant differences were observed near the phantom surface because of the build-up effect caused by the thin-wall thickness of the teflon capsule. Thus, our study showed that the contribution of teflon thin-wall capsule to TLD response for the megavoltage photon beams was negligible and that it did not significantly effect dose measurement. The teflon encapsulated TLD described in this work has been proven to be appropriate for *in vivo* dosimetry in therapeutic environments.

Key Words : Teflon encapsulated TLD, Thin-wall capsule, Response change, *In vivo* dosimetry

INTRODUCTION

In vivo radiotherapy dosimetry (i.e. the monitoring of the actual dose received during treatment) provides a quality assurance check of the accuracy of the tumour dose, and a means of determining the radiation dose to a critical organ outside the main beam, such as the lens of the eye or the spinal cord.[1] Traditionally, treatments have been monitored either by placing dosimeters at the surface of the patient or within an appropriate cavity to ensure that the prescribed doses are correctly delivered to the patients. The dosimeters normally used are either TLDs or semiconductor diodes.[2] TL dosimeters have a number of advantages which make them an useful tool in particular for measurements in anthropomorphic phantoms and for *in vivo* dosimetry on patients.[3] Especially, LiF;Mg,Ti is the most commonly used conventional thermoluminescent dosemeter for dose measurement on account of its good dosimetric characteristics.[4] However, because of its small size and crystalline structure this dosimeter should be carefully handled to eliminate any artifacts that would preclude accurate results.[5] TLDs have to be covered to prevent their direct contact to the patients skin for surface dose measurements or intracavitary measurements.[6]

In order to measure absorbed dose it can be placed within murine or other anatomy; e.g., near or within a normal organ or tumor site. In radioimmunotherapy (RIT) applications, the TLD is embedded in tissue at mammalian body temperature and physiological pH.[7] When determining absorbed doses using TLDs in environments such as tissue culture medium, gel, or mus-

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cle, most significant of the effects observed was the loss of light output with time probably due to crystal leaching. One must realize that such leached dosimeters would be much less sensitive than those which had not been placed in the media. A preferable strategy may be to encapsulate dosimeter in a sheath prior to use in an organism. To address this particular problem, a new experimental model was developed, in which TLD rod was encapsulated by teflon thin-wall capsule. This encapsulating process ensures; (a) mechanical protection of TLD dosimeters; (b) protection of thermoluminescent crystals in a liquid environment.[8] We investigated the alterations of the absorbed dose response using TLD caused by the presence of the teflon thin-wall capsule. In order to estimate the variation of dose with the depth in tissue, the depth dose in solid phantom in the build-up region was measured with and without teflon thin-wall capsule. Measurements were also performed with an anthropomorphic phantom beyond the build-up region. In order to explain this behaviour, the depth dose distribution measured with normal TLD was compared to the depth dose distribution obtained with the tc TLD.[9]

MATERIALS AND METHDOS

1. Calibration of the TLD dosimeters

Exposures of the TL dosimeters were made in the 6 MV x-ray beam of a linear accelerator (CLINAC 600C, Varian, USA). Various thicknesses (1, 2, 3, 5, 10 mm, etc) of RW3 plates (PTW, Feiburg, Germany) were used as solid water phantom for this study. The accelerator was calibrated to deliver 100 cGy per 100 monitor units (mu) in a 10×10 cm^2 field with SSD of 98.5 cm at the depth of maximum dose (d_{max} = 15 mm). All experiments were performed delivering 100 monitor units to avoid problems with the supralinearity of LiF.

A new batch of 100 lithium fluoride (LiF:Mg,Ti) rods (Harshaw TLD-100 extruded rod; dimensions 1 mm diameter, 6mm long; Bicron Radiation Measurement Products, Solon, OH, USA) were used as thermoluminescent dosimeters.[10] The TLD rods were handled with home-built vacuum tweezers using a plastic nozzle to avoid scratching the surface of the rods. A brass annealing tray, having inserts for 10×12 is used to carry the TLDs and they were always returned to their position in the tray to maintain their identification except during irradiation and readout. The TLD rods were readout in a automated TLD reader (Harshaw/ Bicron, TLD reader 5500) in a two step read-out cycle. The readout temperature was 300℃. All dosimeters were annealed in a dedicated annealing oven(PTWO, Freiburg, Germany) at 400℃ for 1 h followed by fan forced cool down to 100℃ which was held for 2 h.[11] The TLD rods was subjected to four initialization cycles. After initialization, four calibrations were carried out in succession. To improve the dosimeter accuracy, individual calibration factors were established for each detector and each rods were calibrated.

2. Teflon thin-wall capsule

In order to use TLD for *in vivo* dosimetry, a container was designed using teflon to accommodate one TLD rod. The size of the container was 8 mm in length, 2 mm in outer diameter, and 0.25 mm thick. The container had a cylindrical hole (diameter : 1.5 mm) at the center to accommodate the TLD rod. The teflon container was made of two bodies (cylinder and end cap) as shown in Fig. 1. Teflon end cap was well matched to the cylinder. This container was referred to in the text as the thin-wall teflon capsule. TLD rod was placed in the thin-wall teflon capsule and named as tc TLD (teflon encapsulated TLD) through out this paper. The TLD rod without a thin-wall teflon capsule was called normal TLD after this. The dimension of the

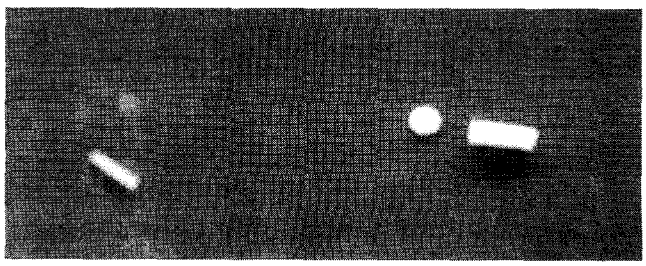

Fig. 1. A normal TLD (left) and the thin-wall teflon capsule with end cap.

tc TLD (8 mm in length and 2 mm in diameter) was still small compared with the typical field sizes used in external beam radiotherapy.

3. PDD with normal TLD and relative dose of tc TLD

RW3 plates of size 30 cm×30 cm with various thicknesses were used as a solid water phantom in the present study. The density of RW3 for this TLD measurements were obtained from literature (1.045 g/cm^3).[12] A hole of 1×6 mm^2 and 2×8 mm^2 was machined at the center of 1-mm and 2-mm thick RW plates to accommodate the normal TLD and the tc TLD, respectively. This plate was sandwiched between other identical RW3 plates to build various thickness of phantom.

PDDs of normal TLD were measured in the solid phantom at 10×10 cm^2 field size using 6 MV photon beam. The radiation was always perpendicular to the surface of the solid phantom. Measurements were performed from the surface to 23 mm in the phantom at 1mm interval by adding additional RW3 plates. Though the phantom thickness was altered by introducing the additional phantom plates, any effect by the air gap thickness between plates was ignored. To provide full scatter condition, additional 20 cm phantom was placed under the dosimeter. The normal TLD rod in a slot of a 1-mm thick RW3 phantom plate was irradiated and then read out at each depth. In PDD measurement with the normal TLD, the position of the detector was changed to maintain a constant SSD of 98.5 cm. The tc TLD in a slot of a 2-mm thick RW3 phantom plate was located at the same position as the normal TLD and irradiated at the same condition. The thin-wall teflon capsule was removed from the tc TLD to read signal. All treatment geometry parameters, except for the TLD, remained same throughout the experiment. The ratio of the readouts between normal TLD and tc TLD at each depth was calculated.

4. TMR with normal TLD and relative dose of tc TLD

The TMR was defined as the ratio of the absorbed dose at a given point in a phantom to the absorbed dose at the same point at the reference of maximum dose depth in a phantom. TMR data were taken at a fixed source-to-detector distance of 100 cm by varying the measurement depth from 0 to 23 mm with 1 mm interval. The position of the plates with the normal TLD and tc TLD not disturbed as the depth of the dosimeter increased. In both cases, 100 monitor unit was deliverd and the signal was read. The ratio of the readout between normal TLD and tc TLD was calculated.

5. Rando phantom measurements with tc TLD

An anthropomorphic phantom (Alderson Rando, University of Chicago, USA) instead of real human body has been used to validate the propose *in vivo* technique of teflon encapsulated TLD (tc TLD). The Rando phantom consists of a human skeleton embedded in synthetic tissue-equivalent material forming the natural body contours. It has no limbs and is divided into 36 separate slices with a thickness of 2.5 cm. Each slice contains a regular matrix of 5 mm diameter holes, 1.5 cm apart. The holes are normally filled with plugs of the same material, which can be inserted by TLD for dose measurement at selected locations.

To study the effect of dose perturbation generated by the thin-wall teflon capsule, 13 dose points on the 26th slice of the human phantom were selected. Fig. 2 was a cross section of the abdomen of the phantom, indicating the position of dose measurements. The phantom was dismantled, and the normal TLDs were placed in a

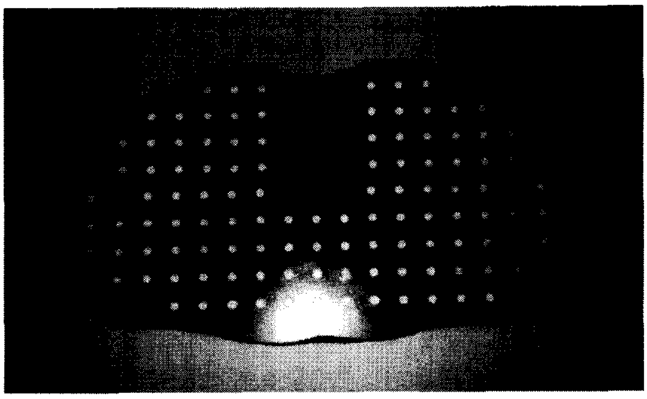

Fig. 2. The cross section of the abdomen of Rando phantom. It indicates the matrix to be numbered. 13 dose points (#1-#9 and #10-#14) on the slice 26 of the phantom were selected.

sequential order of labelled TLD at the pre-determined position in the 26th slice. The phantom was then reconstructed by adding slices numbered from 20 to 32 and the treatment geometry was reproduced. The Rando phantom was positioned on the table in supine position and exposed to AP irradiation. The central axis of the field passed through the 26th slice. For the tc TLD, measurement geometry was same.

RESULTS AND DISCUSSIONS

1. PDD curve of normal TLD and relative curve of tc TLD

The reading of a single normal TLD was normalized to 100 at d_{max} of 15 mm. The results of these measurements with normal TLD and tc TLD were shown in Fig. 3 and the ratio of the tc TLD dose to the normal TLD dose were shown in Fig. 4 for relative comparison. The ratio was obtained dividing the tc TLD value by noraml TLD value. Horizontal solid line as 1 was related with the value of a normal TLD. Any deviation above the horizontal axis represented an over response of the tc TLD dose, while any deviation below the horizontal axis represented under-response of the tc TLD dose compared. A zero deviation implied that the tc TLD dose was equal to the dose measured by the normal TLD. Significant differences of up to 40% was observed in the 0 to 4 mm depth range. The over-response was attributed to the build-up effect of the teflon thickness of thin-wall capsule. But for the depths greater than 5 mm, the difference was less than 3%. The resulting batch of 50 rods were used in this experiment. For each dosemeter used, the standard deviation of the sensitivities measured in the four calibrations was about 2%. Additional uncertainty in dose was estimated to be <1% due to machine output variability and <2% due to measurement setup variability. Assuming normal distribution and independence of these uncertainties, the square root of the sum of the squares of these values gave a total dose uncertainty around 3%.[13] The measured dose differences were not significant because they are less than the experimental error of TLD.

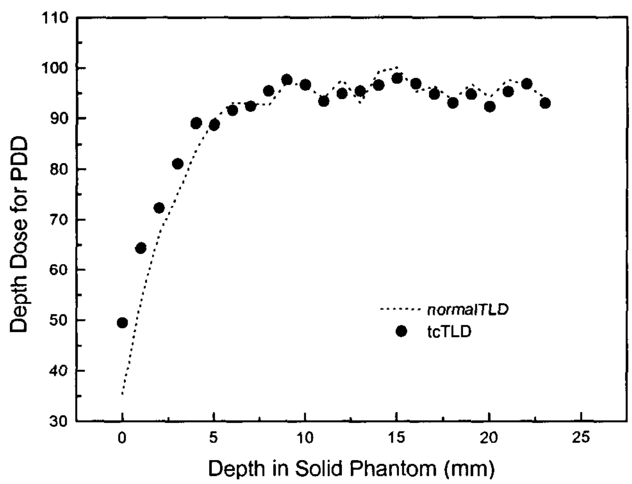

Fig. 3. Depth dose curves. Percentage of depth dose was obtained by the normal TLD for a 10×10 cm^2 square field at the SSD 98.5 cm for 6 MV linear accelerator. The both dosimeter's responses were evaluated and normalized to the value of normal TLD at 15 mm depth in the phantom. The result of normal TLD measurement is shown by a dotted line. For comparison also the depth dose measured with a tc TLD at the same condition is shown by scattered circles.

2. TMR curves in the solid phantom

The results of TMR measurements were shown in Fig. 5. The reading of a single normal TLD was normalized to 1 at d_{max} of 15 mm. The TMR measured with a tc TLD in the solid phantom was shown by

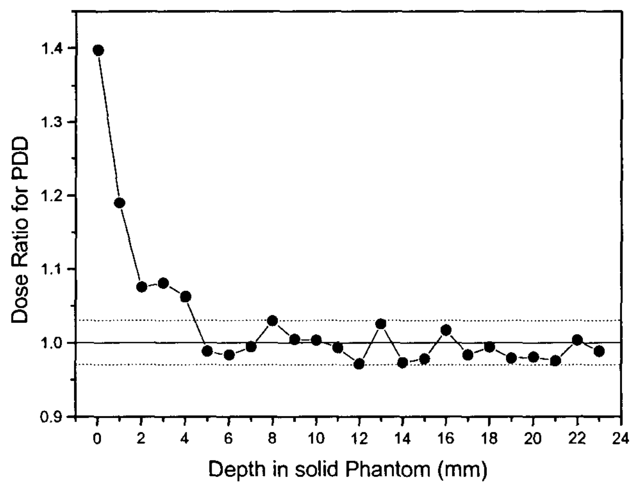

Fig. 4. The ratio of the tc TLD dose from the normal TLD dose in PDD. Fig. 3 shows the results of the dose ratio; this corresponds to the tc TLD response divided by normal TLD response. The evaluation of a normal TLD is shown as 1 with a horizontal solid line.

scattered circles. For comparison the ratio of the tc TLD dose from the normal TLD dose was calculated at all depth. Fig. 6 showed the results of the dose ratio; this corresponded to the tc TLD response divided by normal TLD response at each depth. We observed that tc TLD showed an over-response of up to 30% at the phantom surface as compared to that of normal TLD. But the enhancement in the response was not more than 10% at shallow depth less than 3 mm from the phantom surface as compared to that of normal TLD. However, the difference in response at the depths between 4 mm and 23 mm from the surface did not change by more than 3% which is within the experimental error of TLD.

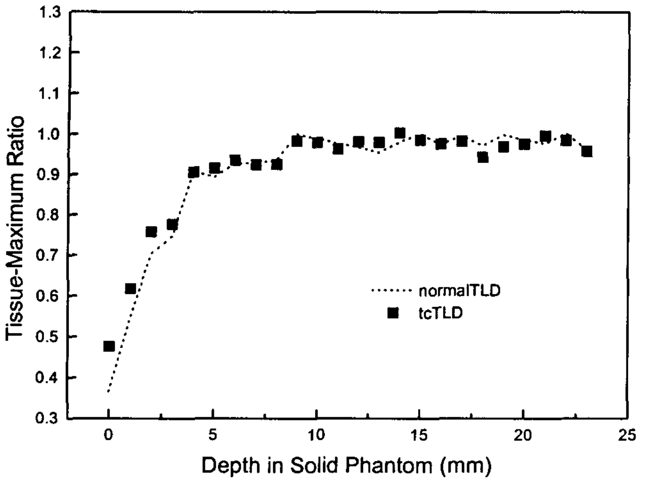

Fig. 5. The TMR curve of TLD. In order to measure the TMR with tc TLD or the normal TLD, the irradiation depth was varied between 0 and 23 mm for a 10×10 cm^2 square field at the standard SAD 100 cm. The both dosimeter's responses were evaluated and normalized to the value of normal TLD at 15 mm depth in the phantom. The TMR measured with a normal TLD in the solid phantom is shown with a dotted line. The result of tc TLD measurement at the same condition is shown by scattered squares.

3. Absorbed doses in humanoid phantom

The results of TLD measurements obtained with 6-MV photon, both with and without teflon thin-wall capsule, were shown in fig. 7. The measured dose in each dosimeter was given as a function of physical depth in Rando phantom. A comparison between doses at the same sites between tc TLD and normal TLD was performed. Fig. 8 showed the results of the dose ratio. For all measurements, the differences were less than ±3%. The sources of error in the determination of humanoid phantom dose included uncertainty existing in thermoluminescent dosimetry and variations of TLD position. We found no significant differences between normal TLD response and tc TLD response in the abdomen part of the humanoid phantom.

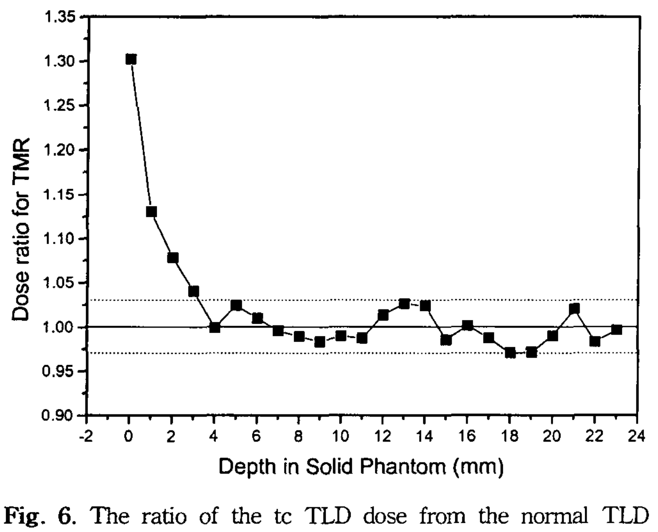

Fig. 6. The ratio of the tc TLD dose from the normal TLD dose in TMR. It was calculated at all studied depth. The dose ratio corresponds to the tc TLD response divided by normal TLD response at each depth. The value of a normal TLD is shown as 1 by a horizontal line.

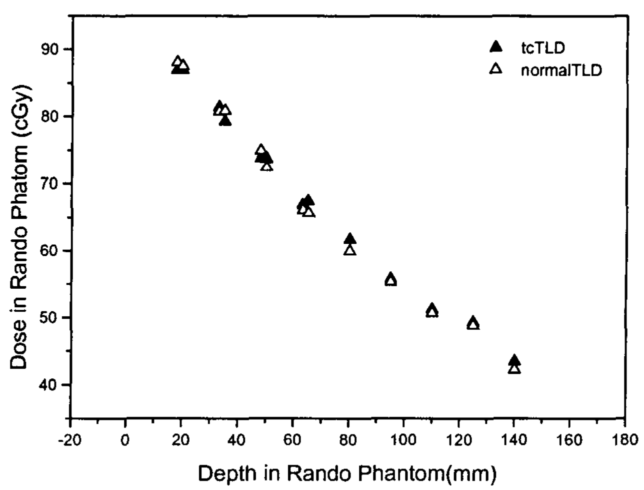

Fig. 7. The dose measurements in the abdomen region of a humanoid phantom with tc TLD and normal TLD. The measured doses in each dosimeter at the same sites are given as a function of physical depth in Rando phantom.

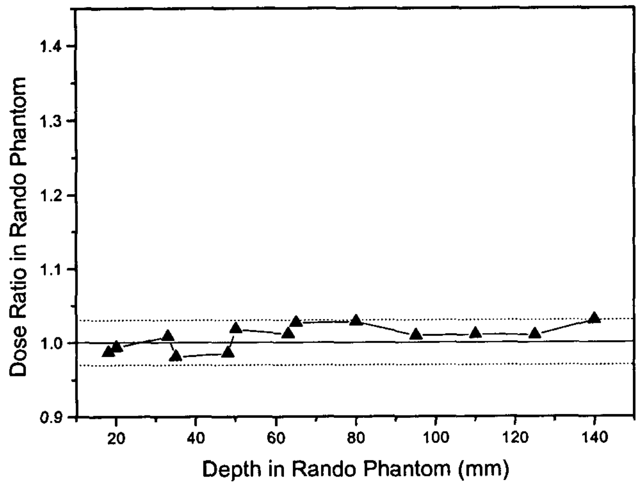

Fig. 8. A comparison between doses at the same sites between tc TLD and normal TLD. The dose ratio corresponds to the tc TLD response divided by normal TLD response. The reading of a normal TLD is shown as 1 with a horizontal line.

CONCLUSIONS

The use of TLD without covering material cause problems in obtaining reliable and accurate signal for *in vivo* study. To address this problems, a new experimental model was developed, in which TLD rod was encapsulated by teflon thin-wall capsule. The objective was to measure the change of dose caused by a teflon thin-wall capsule in TLD. It was assumed that the differences were caused by the presence of the thin-wall teflon capsule. In order to estimate the variation of dose with the depth in tissue, the depth dose in solid phantom in the build-up region was measured with and without teflon thin-wall capsule. Measurements were also performed with an anthropomorphic phantom by tc TLD and normal TLD beyond the build-up region.

Experimental studies showed that the dose ratio of tc TLD and normal TLD was less than 3% except build-up region. This indicates that the use of tc TLD as a *in vivo* dosimetry is possible without causing significant perturbation effect on TLD signal beyond build-up region. Thus it can be concluded that there is no difference between the response of the normal TLD and the tc TLD as long as the detectors are not placed near the surface of the phantom. The present study thus shows that the contribution of teflon thin-wall capsule to the TLD response for the megavoltage photon beams is negligible to cause any significant change in the measurement of doses. This tc TLD thus appears to be a viable alternative to the use of normal TLD dosimeters when this new thermoluminescent dosimeter is used in a therapeutical environment.

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생체 내 흡수선량 측정을 위한, 얇은 테프론의 TLD 반응감도에 대한 효과성

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본 연구의 목적은 핵의학 분야에서 생체 내 흡수선량의 직접 측정에 사용될 수 있는, 테프론을 씌운 TLD의 수행성을 알아보고, 흡수선량 측정 시 테프론의 영향에 대하여 분석하고자 한다. 테프론 캡슐에 든 LiF TLD-100의 반응감도를 고체 팬텀 내에서의 깊이를 달리 하며 측정하였다. 성인 인체모형 팬텀을 이용하여 테프론을 씌운 TLD로써 생체 내 흡수선량을 측정하였다. 테프론을 씌우지 않은 보통의 TLD를 이용하여 구한 PDD, TMR, 그리고 생체흡수선량과 테프론을 씌운 TLD로 구한 값을 비교하였다. 보통의 TLD를 이용하여 구한 반응값과 테프론을 씌운 TLD로 구한 값의 차이는 build-up이상의 깊이에서는 같은 조건하에서 3% 이내였다. 그러나 팬텀 표면 부근에서는 테프론 캡슐의 두께에 기인한 build-up 효과로 인해 큰 차이를 보였다. 본 연구에서 테프론 캡슐로 인하여 수 메가볼트의 방사선에 대한 TLD의 흡수선량 측정에 미치는 변화는 미미한 것으로 나타났다. 따라서 치료 환경 하에서 테프론을 씌운 TLD가 생체 내 선량측정에 매우 적합한 것으로 사료된다.

중심단어 : 테프론을 씌운 TLD, 테프론 캡슐, 반응감도 변화, 생체 내 흡수선량