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The Roles of Gold Plate (140 μm) Loaded on TLD-100 Chips in the High Energy Radiation Beams

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Abstract

Abstract Lithium Fluoride (LiF ; TLD-100) crystal chips are normally used as thermoluminescence dosimeters (abbreviated as NC-100) for estimating the absorbed dose to the skin of a patient or in a solid water phantom undergoing radiotherapy with megavoltage photon (6 and 15MV) beams.

In general, investigation has revealed a reduction in the sensitivity of NC-100 chips after many runs through heating cycles. A TLD-100 chip laminated with gold plate (140μm) on the upper surface layer of its face toward the photon beam (abbreviated as GC-100) has properties different from that of a NC-100 chip activated by incident photons and contaminant electrons with various lower energies coming from the gantry head and air. Activation of the valence band electrons of GC-100 chips by incident photons, positrons and electrons-which come from the gold plate by mainly pair production process and partly from Compton scattering-results in more enhanced signal intensity , higher response per monitor unit, as well as a good linearity with monitor units and independence of dose rate. Since the electron beams (6 and 15 MeV) do not have the probability of pair production process with gold plate, there is only a small difference (about a 3.3% increase for 15 MeV) in the signal gaps in the TL readout for electron beams between GC- and NC-100 chips. The 3.3% increase is entirely due to the buildup caused by the 140 m gold plate. The sensitivity of GC-100 chips is much more susceptible to high energy photon beams than electron one because of pair production. The interaction of high energy photon with a material of high atomic number, such as the gold plate in this case, results in a considerably significant probability of pair production. The gold plate on the NC-100 chips acts as not only an intensifier of their signals but also acts as a filter of contaminant electrons in therapeutic high energy X-ray beams.

1. INTRODUCTION

Thermoluminescence dosimeters (TLD) are used to confirm absorbed dose estimates at specific positions in a radiation beam, either directly on the skin of a patient or in a The stress distribution of bone is altered by the rigid bone plate, sometimes resulting in unfavorable osteoporosis. The rigidity and the biocompatibility are important factors for the design of prosthesis, however, it is also necessary to consider the effect on the bone remodeling. In this paper, it is attempted to establish an approximate and simple method to predict the trend of the configuration of surface bone remodeling upon a bone plate using stress analysis. Thus, three dimensional finite element model of plated-human femur is generated and simulated. In addition, the stress difference method (SDM) is introduced and attempted to demonstrate the configuration of surface bone remodeling of the plated-human femur.

solid water phantom. Furthermore, TLD-100 is used by the Radiological Physics Center (RPC) for mailed dosimetry for verification of therapy machine output.[1]

TLD consists of a host crystalline material containing one or more activators that may be associated with the traps, luminescence center, or both[2]. Amounts of activators range from a few parts per million up to several percent in different phosphors. The host crystal almost entirely determines the radiation interactions, since the activators are usually present in such small amounts[3] LiF crystal chips doped with magnesium about 300ppm and titanuim abut 15ppm were used as stndard chips ($3.2\times.3.2\times0.9mm^3$) All investigated measurements TL dosimeters were made from LiF containing the natural isotope mixture of lithium such as TLD-100[4].

In this study the relative importance of the Compton scattering and pair production process depends on both the photon quantum energy and the atomic number Z of the absorbing medium[4]. The probability of pair production resulting from interaction of the photon with the medium is more dominant for higher photon energy and higher Z media than lower Z ones. When the energy of the photon is greater than 1.02 MeV, for 6 or 15 MV beams, the photon interacts with matter of high atomic number (Z) such as a gold plate (140 μm) through the mechanism of pair production process. The photon interacts strongly with the electromagnetic field of a gold atomic nucleus and gives up all its energy in the process of creating a pair consisting of a negative electron and a positive electron[6].

In the TLD-100 chip produced by Harshaw Chemical Co., the traps are normally filled with electrons. 'A photoelectron or Compton electron (produced by an X-ray photon) will elevate other electfrons out of the valence band into the conduction band leaving a hole in the valence band[6]. If an electron in the trap requires energy (by heating) to get out of the trap and fall to the valence band, allowing luminescence production. The flux of high-speed electrons and positrons (caused by Compton and pair production absorption process) deposit energy within irradiated TLD-100 by high energy photon beams, which later can be released as TL readout7. These sorts of electrons might make the signal intensity enhanced. The gold plate ($3.1\times3.1\times0.14$ mm^3) on the surface of the NC-100 chips acts as an absorber and intensifier, i.e., a source of high energy positrons and electrons, an injector of electrons, positrons, and parts of the incident photons into the NC-100 crystal chips. Consequently in GC-100 chips there are many more effects of excitation of the electrons in the valence band than in the case of NC-100 chips. After the GC-100 chips were irradiated by photon beams, the signals of the GC-100 were greater and had more accuracy and precision of reading reproducibility than that of NC-100chips. The irradiations with high energy photon beams were made both with (GC-100)and without gold plate (NC-100)at 10×10cm field size on a 15cm thick phantom[8] plate surface at 100cm SSD.

This study describes the measured results used to estimate the suitability of GC-100 chips for the measurement of surface dose in a megavoltage photon beams.

2. MATERIALS AND METHODS

LiF(TLD-100;NC-100) produced by Harshaw has been by far the most commonly used TLD phosphor, partly because of its low effective atomic number, only slightly greater than that of tissue and air[9]. In this case NC-100 chips ($3.2\times3.2\times0.9mm^3$)laminated with gold plate (GC-100)were used. All NC-100 and GC-100 chips were read in a Harshaw TLD system 4000 reader fitted with the research module. The heating cycle was preset for a preanneal of 5 seconds at 100℃, aquisition time for 30 seconds, beating rate 10℃ $s^{-1}$and an anneal of 5 seconds at 300℃. The reader gate set by means of glow curves to investigate the TL signal over the two main peaks but much of the unsolved shoulder on the high temperature side of the 300℃ peak was cutout. All chips were annealed (1hr 400℃ followed by 2hr 100℃)in a TLD annealing oven(PTW, TLDO) after each readout to minimize sensitivity drift. Also, all chips were annealed in a clean PYREX container. It was noted that contact with any metal container may damage NC-100 chips during annealing cycle (Harshaw/Filtrol, 1990)[1)]. In general TL phosphors give the best performance as dosimeters if they receive uniform, reproducible, and optimal (depending on the phosphor) heat treatment befor after use.

Exposures of the NC- and GC-100 chips were made in the 6 and 15 MV photon bectron of a Varian linear accelerator (Clinac 1800) on the surface of a 15 cm thick polystyrene plate (Victoreen, SCRAD Calibration Phantom) as the phantom material at a field size of 10 10 cm2 and 100 cm SSD. The NC- and GC-100 dosimeters were arranged as seen in Fig.1 (free lying on the surface of the polystyrene phantom in the central beam at 100 cm SSD).

The apparatus shown in Fig.1. is normally used for the calculation of the dose to the skin of the patient. The experiments were accomplished with a maximum dose of 300 monitor units recommended by RPC (from 10 to 300 monitor units) in order to validate the supralinearity11 of NC- and GC-100 chips. A total of ten TLD-100 (NC-100) chips were divided into two groups used twice for a total of four measurement groups. The first group of five TLD-100 chips (NC-100) was irradiated by a 6 MV photon and electron beams, the second group of five other NC-100 chips was irradiated with a 15 MV photon and electron beams in the same fashion. The third group was the first measurement group laminated with gold plate (GC-100) and irradiated by a 6 MV photon and electron beams, the fourth group was the second measurement group laminated with the same gold plate (GC-100) irradiated by a 15 MV photon and electron beams. After the GC-100 chips were irradiated by 6 MV or 15 MV photons and electrons, we necessarily removed only the gold plate on the GC-100 chips to read the TL readout from the underlying NC-100 chips affected by pair production from the gold plate using a TLD 4000 reader unit. This process was necessary in order to avoid damaging the NC-100 chip crystal material during data aquisition by the heating cycle.

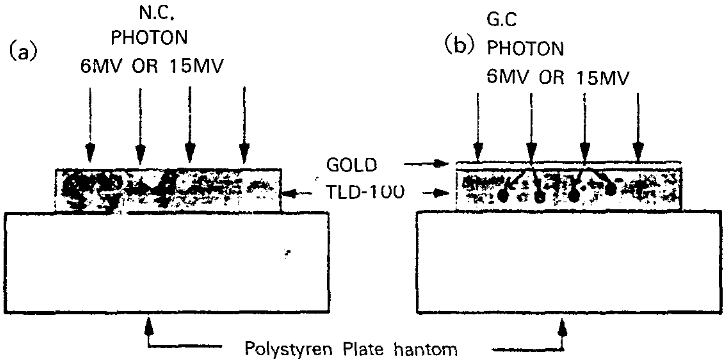

Fig.1. The schematic of a normal chip (TLD-100 ; NC-100) and a TLD-100 chip laminated with gold plate (GC-100) in measurements of surface dose for 6 or 15 MV photon and electron beams at 10x10 cm^2 field size and 100 cm SSD on a 15 cm thick polystyrene plate phantom. a) NC-100 chips irradiated by 6 or 15 MV photon and electron beams, b) GC-100 chips irradiated by 6 or 15 MV photon and electron beams.

3. RESULTS AND DISCUSSION

The readings show the dose responses of NC-100 and GC-100 chips perunit dose as a function of absorbed dose in cGy in Fig.2. The general shape of these curves are linear up to about 300 cGy recommeneded by RPC with a small degree of supralinearity at intermediate dose levels between 200cGy and 300cGy. From 10cGy to 200cGy monitor units the dose responses for NC-and GC-100 are all closely independent of the absorbed dose. At 300cGy dose GC-100 and NC-100 are both a little high because of supralinearity ; 8% high for NC-100, 5% high for GC-100 chips. Since the gold plate acts as an intensifier of signal intensities, GC-100 chips give a 100± 1 % increase in dose response as compared to NC-100 chips for 15 MV photon beam. Additionally, GC-100 chips showed superior sensitivity even after many heating cycle runs. As was expected, the different signal intensity between the GC- and NC-100 chips was mainly the effect of the increase in pair production resulting from the interaction of the high energy photon beam with a high atomic number material such as the gold plate (140μm), which is equivalent to 1.90 mm thick tissue, as compared to the material of the NC-100 crystal chips.

GC-100 and NC-100 chip were irradiated with a linear accelerator 15 MV photon beam

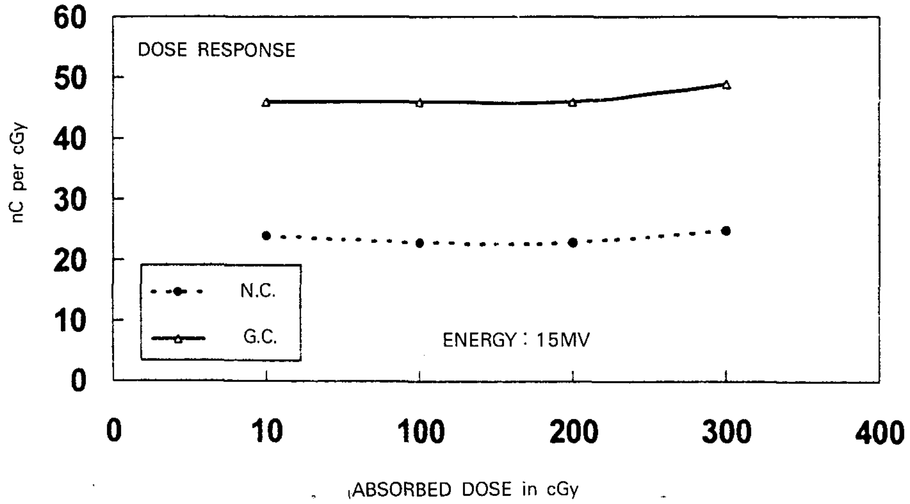

Fig.2. The plot of TL readout (arb. unit) against per monitor units gives the dose response curve of GC- and NC-100 chips. The general shape of this curve is linear up to about 300 monitor units with a small degree of supralinearity at intermediate dose levels between 200 and 300 monitor units.

within a range of absorbed doses up to 300cGy .nonitor units. All TL readout normalized with respect to the signal of NC-100 chips reading irradiated with 100 monitor units by 15 MV photon beam are plotted in Fig.3. They are both linear up to 200 monitor units with a small degree of supralinearity less than 2 %, but at dose higher than 200 monitor units are on the order of 5 %. This discrepancy was found for all different chips thus readings were corrected for that error if it was encountered.

In the case of Fig.3, supralinearity is shown to some extent by most TL phosphors, and may be due to the increased availability of luminescence centers when the charged-particle tracks become closer together, or to radiation-induced trap formation, or to other causes. At large enough doses all thermoluminescence phosphors either saturate in their output as all available traps become filled, or maximize and then decrease due to radiation damage of the phosphor3.

The GC-100 chips which had a higher dose response than that of NC-100 chips are fortunately also independent of dose rate range in megavoltage photon beams in Fig.4. Since GC-100 chip dosimeters have a properties of higher response, good linearity, independence on dose rate, the relative errors for TLD measurements are 0.5 % for GC-100 and 1.8 % for NC-100 chips for 6MV and 15MV photon beams. and if they were calibrated by exposing the dosimeter to known amount of radiation, GC-100 chip can be suitable for the measurement of point dose on the surface or dose in the phantom because it's size being small.

Typically one or two in ten NC-100 chips indicated an abnormally high or low reading

(10 % more or less than the mean reading of a set). These chips were ejected from the calculations. By keeping each chip separately identified we were able to use the relative sensitivity of each chip ; this was repeatable within 1.5 %. The reasons why GC-100 chips had a smaller relative error than that of NC-100 was because for a given high photon energy, there were a constant probability of emission of positrons and electrons from the gold plate (140μm) by mainly pair production process and the gold plate might be some shielding from contaminant electrons with various low energies unwanted coming from the gantry head and air. In the case of NC-100 chips, there are a constant probability of emission of Compton electron in the NC-100 chip crystal from the Compton process, but there are a lot of contaminant electrons with various low energies in the central photon beam12. These contaminant electrons made a larger relative errors of the signals of NC-100 as compare to the signals of the GC-100 chips.

The results summarized in Table I show the TL readout of NC- and GC-100 chips at the surface of a 15 cm thick phantom plate normalized with respect to the absorbed monitor units of the signal of NC-100 chips for 15 MV photon.

GC-100 chips give a 100± 2% increase for 15 MV and 168± 2% increase for 6 MV photon in dose response. The normalized readout indicated a 33 % difference between the signals of 6 and 15 MV irradiated NC-100 chips, whereas the GC-100 chips nearly had a 20 % difference between them. The GC-100 chips displayed greater energy independence as well as a small fluctuation of error than that of the NC-100 chips.

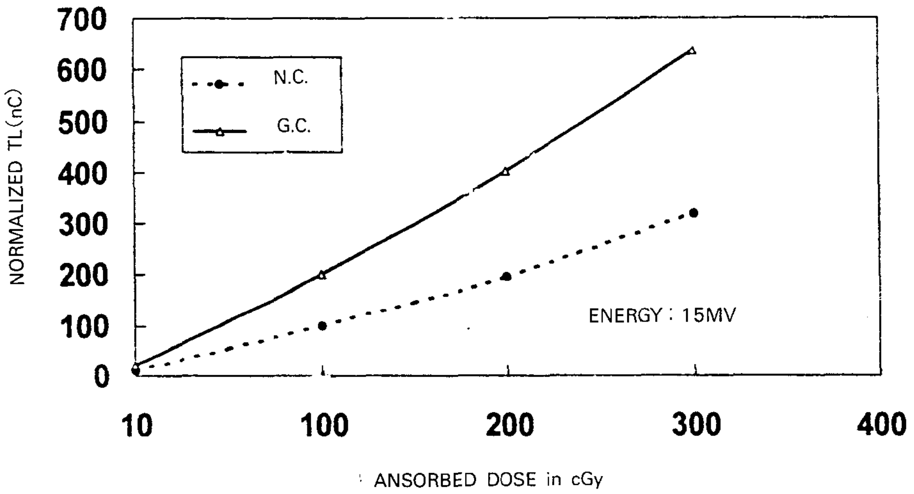

Fig.3. The linearity and supralinearity of GC-100 and NC-100 chips thermoluminescence (TL in arb. units) as a function of monitor units for the 15 MV photon beam at 10x10 cm2 field size and 100 cm SSD with a small degree of supralinearity at intermediate dose levels between 200 and 300 monitor units.

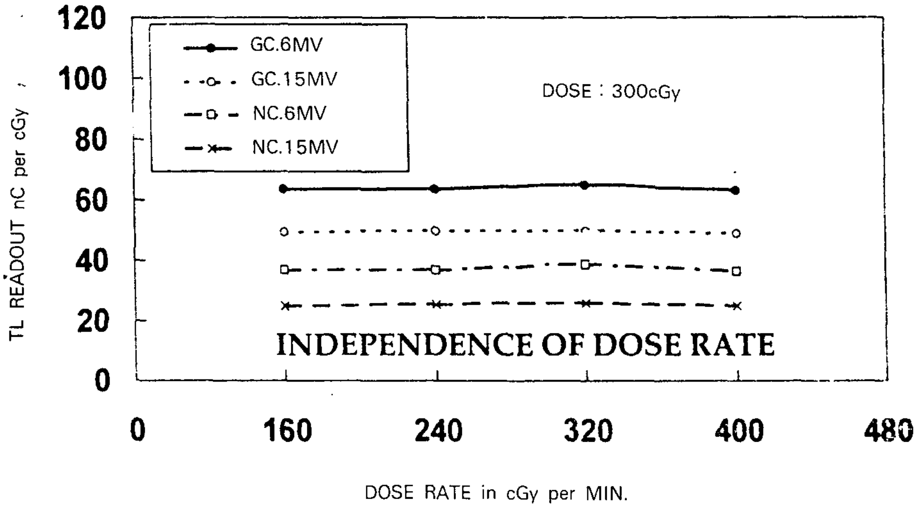

Fig.4. The NC- and GC-100 chip are independent of dose rate from 160 monitor/min to 400 monitor/min for both 6 and 15 MV photon beams at 10x10 cm^2 field size and 100 cm SSD. The independent dose response of GC-100 had a higher intensity than that of NC-100 chips.

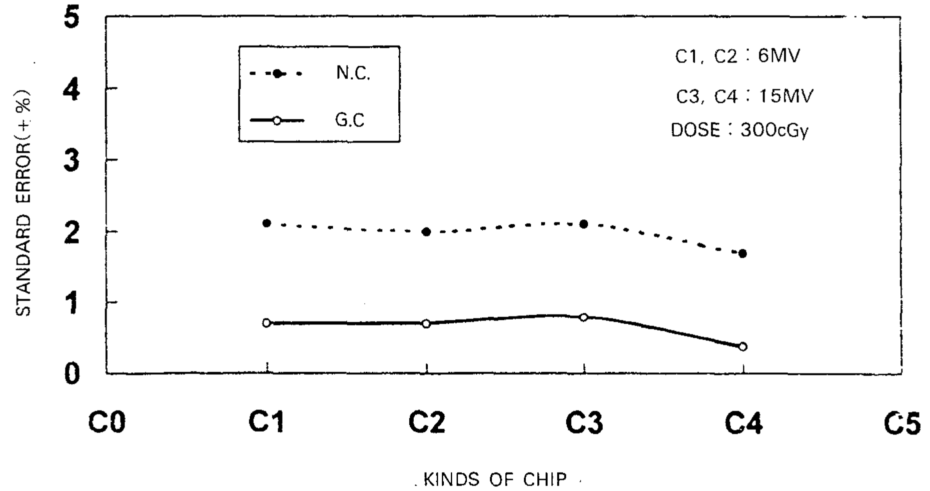

Fig.5. The plot of fluctuation of standard error (± %)against GC-100 and NC-100 chips for both 6MV and 15MV photon beams at 10×10cm field size and 100cm SSD. The accuracy and precision GC-100 had a higher reproducibility than that of NC-100 chips. *Harshaw /Filtrol Chemical Co., TLD manual, 1990%

4. CONCLUSION

TO make or handle GC-100 chips is very simple and this process can be applied to all kinds of TLD chips. GC-chips have not only a good linearity but also have a reading reproducibility accuracy and precision good within 1 %. Experimently, the acucracy and precision of GC-100 had a higher reproducibility than that of NC-100 chips and increased more for the higher photon energy (15 MV) than the lower one (6 MV).

In view of the results so far achieved, GC-100 chips have a useful role to perform in the measurement of skin dose (entrance and exit dose) or dose in solid water phantom in megavoltage radiotherapy.

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Table1. The relative TS readout of NC and GC-100chips for 10×10cm^2 field size and 100cm SSD on a 15cm thick polystrene plate phantom for 6MV or 15MV photon beams with 300cGy.

Readout	Measurement groups			
	NC0-100(6MV)	NC-100(15MV)	GC-100(6MV)	GC-100(15MV)
Relative TL readout (nC/cGy)	150± 1	100± 0.0	252± 2	200± 2
Fluctuation of error(%)	1.8± 0.1	1.6± 0.1	1.3± 0.1	0.5± 0.1
Lineanty from 10 to 300 monitor units		good		good
Dose rata from 160 to 400Mu/Min	Indep	Indep	Indep	Indep

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The Roles of Gold Plate (140μm) Loaded on TLD-100 Chips in the High Energy Photon Beams

고에너지 광자선속에서 TLD－100 chip 위에 있는 금박막(140μm) 역할

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초 록

고에너지(6-15MV) 광자선속으로 치료할때 LiF(TLD-100)결정은 solid water phantom이나 환자의 피부 표면에서의 흡수선량을 측정하기 위해 열자극 발광 선량계(이하 NC-100)가 주로 사용된다. 통상 NC-100은 가열 과정을 여러회 반복하면 그 감도가 줄어드는 것으로 조사되었다.

NC-100위에 입사 광자선속 방향으로 올려놓은 140μm 두께의 금박막(이하 GC-100)은 NC-100과 다른 성질을 갖는다. 즉, 광자선속에서 GC-100은 금박막에서 주로 쌍생성이 일어나고 부분적으로 Compton 산란이 일어나 많은 양전자와 음전자를 만들어 낸다. 그 결과 TLD-100 결정은 증가된 신호를 갖고(최대 100%증가), 흡수 선량당 높은 반응도가 좋은 선형도를 갖으며, 선량물에 무관할 뿐만 아니라 Fluctuation error 도 ±0.5%미만으로 낮게 측정되었다.

GC-100은 주로 쌍생성이 일어나기 때문에 전자선보다 광자선에서 더욱 감도가 좋은것으로 나타난다. 그것은 금과같이 원자번호가 높은 매질에서 광자선에 의한 쌍생성의 확률이 큰것에 기인한다.

치료용 고에너지 광자선속에서 TLD-100 chip 위에 올려진 금박막은 TLD의 신호를 크게 증가시키는 역할을 하는것으로 나타났다.