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Comparison audit program for selected radiotherapy centers by secondary standard dosimetry laboratory (SSDL) using thermoluminescence dosimeter

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HIGHLIGHTS

- Feasibility of conducting a comparative dosimetry audit program for medical centers, by SSDL, has been investigated.
- Using TLD-700 chips, instead of its powder, has Sufficient precision for therapeutic photon beam dosimetry.
- This work can be conducted annually, in order to control the amount of dose delivered to the patients.

ABSTRACT

The International Atomic Energy Agency (IAEA), sends dosimeters annually to Secondary Standard Dosimetry Laboratories (SSDL) around the world, to calibrate their radiation field. Therefore, they mainly send thermo-luminescent dosimeters as transfer dosimeters to the SSDL laboratories, to be irradiated under the requested conditions and sent back to the IAEA laboratories for reading. In this way, by reading the dosimeters, the uncertainty of the dosimetry carried out by SSDL and, consequently, the calibration of its radiation fields is determined. In this research, with the aim of feasibility of comparative dosimetry program by SSDL laboratory for radiation therapy centers, this program was carried out for a number of centers. In this way, TLD-700 thermoluminescence dosimeters were irradiated in the same conditions in the SSDL laboratory and also in the selected centers to a certain amount. After reading and applying the correction coefficients and calibration factors, the obtained results were compared with the measurement results using ion chamber reference dosimeter. In this work the uncertainty of the dosimetry using TLD tablet was less than 1.12% in comparison to the reference ionization chamber dosimeter and was within the acceptable range of less than 3%.

KEYWORDS
Comparison dosimetry
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TLD-700 dosimeter

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1 Introduction

The field of radiotherapy, being a key pillar of modern cancer treatment, has seen significant advancements in the past few years. These advancements have paved the way for more effective and targeted treatments that have the potential to increase the survival rate of patients. Moreover, the newfound methods are also known to result in less severe side effects, thus improving the quality of life of patients undergoing treatment. However, the overall quality and success of radiotherapy treatments heavily hinges upon the precise dose of radiation that is delivered to the patient. Inaccuracies or even minute variations in this critical dose can lead to the unfortunate circumstance of the treatment becoming ineffective. Worse still, it can cause unnecessary harm and damage to the patient's healthy tissues, which can equate to additional physical discomfort and potential complications. Therefore, the importance of ensuring the absolute accuracy of the delivered doses in radiotherapy centers cannot be overstated. It is a crucial aspect that demands the highest degree of attention and precision, as it directly impacts patient outcomes.

The International Atomic Energy Agency (IAEA) in collaboration with the World Health Organization (WHO) conducts a dosimetry program using thermoluminescence dosimeters (TLD) for the calibration of the radiation field

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of radiation therapy devices in developing countries. The main goal of this program was to create an independent quality control program of the dose delivery to patients by radiotherapy devices, using TLD as a transfer dosimeter.

With the aim of achieving agreement on current dosimetry, in all countries a comparative TLD dosimetry program is used to monitor the activities of secondary standard dosimetry laboratories (SSDL). Currently, this program is carried out for thousands of radiation fields used in radiotherapy, and in many cases, major mistakes have been observed in the radiation field calibration of radiation therapy devices, which has prevented incorrect treatment of patients. Also, this has supported the national quality control programs based on TLD, which have been established in developing countries with the support of the IAEA (Izewska et al., 2020, 2008, 2003; Eisenlohr, 2010).

Iran's SSDL laboratory is a member of the international network of SSDLs and serves as a communication unit between primary standards of dosimetry and radiation users at the country level. The activities of the SSDL laboratory are under the IAEA's supervision through the calibration of standard dosimeters and participation in the international intercomparison dosimetry program. It is necessary to remember that during the membership period of SSDL laboratory of Iran, in the international network of SSDLs, the results related to participation in international comparative dosimetry program have been very favorable, which confirms the precision and accuracy of SSDL laboratory services in dosimetry and calibration. At present, the SSDL laboratory conducts annual visits to all radiation therapy centers for dosimetry and quality control of their radiation field. It also calibrates the ionization chambers of radiation therapy centers by having ionization chambers that are calibrated in the IAEA's PSDL laboratory. In order to exercise more control over the dose delivery to patients by radiation therapy centers, the annual comparative dosimetry program of the SSDL laboratory for radiation therapy centers can be launched at the country level using the TLD dosimeters. In this research, with the aim of feasibility of implementing a comparative dosimetry program for all radiation therapy centers, this program is planned for selected centers. With the successful implementation of this research and the removal of the existing obstacles to its implementation, it is possible to implement a comparative dosimetry program using the TLD dosimeter for all centers in the country (Musolino, 2001; Huntley and Izewska, 2000; Izewska et al., 2002; Maleki et al., 2017).

2 Materials and Methods

The dosimeters used in the IAEA/WHO comparative dosimetry program are 155 mg of TLD powder that has been heat treated and poured into the capsules. Typically, the IAEA uses black polyethylene cylinders with an internal height of 20 mm, internal diameter of 30 mm, and wall thickness of 1 mm. The material that is usually used in this program is TLD-700 powder (lithium fluoride powder) as follows:

$$\begin{aligned} &^{7}\text{Li } (99.96\% \ ^{7}\text{Li and } 0.04\% \ ^{6}\text{Li}) \\ &\text{type TLD-700, LiF:Mg, Ti} \end{aligned} \tag{1}$$

Before use, TLD powder undergoes a thermal process. Since the dosimetry characteristics of LiF powder are closely related to its particle size and homogeneity, after heat treatment, the powder is meshed to remove smaller particles (below 80 μm). Before use, this powder is stored for two weeks to stabilize its sensitivity. Then, the powder with a certain weight (155 mg) is irradiated and read with a TLD reader system to determine their calibration coefficients. After that, the heat treatment is done again until they become zero.

The powder is poured into polyethylene capsules and sent to the desired centers to be irradiated according to the instructions and returned. After returning, the powders are read separately and after making the necessary corrections, the amount of radiation of the powders is compared with the requested amount in order to evaluate the dosimetry accuracy of the desired center (Izewska et al., 2020, 2008).

The use of TLD chips for dosimetry has fewer operational problems due to the available facilities, so in this plan, the beam field of several photon accelerators at radiation therapy centers are measured using TLD-700 chips, and compared with the results obtained by the SSDL laboratory. Also, in the same conditions, the dosimetry of the mentioned fields has been done using PTW, Farmer, 0.6 cc ion chamber reference dosimeter and compared with the results obtained from dosimetry using TLD-700 chips.

2.1 *Radiation field dosimetry using TLD-700 chips*

2.1.1 Heat treatment

In order to increase the sensitivity of powders and fading reduction, heat treatment is necessary. The chips were annealed at 400 °C in a high-temperature oven for one hour. After the high-temperature annealing, the chips were rapidly cooled to room temperature. After approximately 30 minutes, they were annealed for a second time at 80 °C in an oven for 24 hours, and were again rapidly cooled to room temperature. The chips were then irradiated at a known dose.

2.1.2 Dosimeter reading

By setting the heating rate, reading time and maximum temperature in the reader, the dosimeter was read in pure inert atmosphere (nitrogen gas) and the stored information was discharged. The unit of discharged Tl is nC in integrator readers and number (number of Tl photons) in photon counting readers. In this research, the samples were read using the Harsha 4500 reader (Fig. 1).

Figure 1: Harsha model 4500 reader used in this project to read dosimeters.

2.1.3 Determination of Element Correction Coefficients (ECC)

Due to the difference in the weight and sensitivity of the dosimeters, it is necessary to determine the correction factor of each dosimeter. For this purpose, all dosimeters were irradiated in a uniform beam field after thermal treatment, in order to discharge information, and then read then, using Eq. (2), the sensitivity of each dosimeter was determined. If the dosimeters used have equal sensitivity, the values of Ecc are close to one. The Ecc coefficient for a specific dosimeter (element) represents the ratio of the average reading for the entire group of used dosimeters divided by the corresponding dosimeter reading. Typically, the group of dosimeters used for regular field use have deviations as large as 25 to 30% from the mean value. The purpose of obtaining Ecc coefficients is to determine the sensitivity of each TLD to other TLDs in order to estimate the dose, accurately. In this work, after heat treatment, all the TLDs were irradiated with a fixed amount of 0.5 Gy using a Co-60 source. After irradiation and reading the dosimeters, the ECC coefficients are obtained from the following equation:

$$ECC_i = TL_{(\text{Average})}/TL_i \tag{2}$$

where, TL is the thermoluminescence read-out and ECC is the elementary correction coefficient of the TLD pellet.

2.1.4 Background correction

It is necessary to consider several dosimeters as control or background dosimeters for dosimetry. These dosimeters are used to correct the radiation effects caused by background radiation and other unwanted radiation. Control dosimeters also need to be preheated together with other dosimeters before reading and read together with irradiated dosimeters. To obtain pure TL, the response of the control dosimeters must be subtracted from the response of irradiated dosimeters.

$$TL_{\text{net}} = TL_{\text{Gross}} - TL_{\text{BKG}} \tag{3}$$

where, TL_{Gross} is the non-pure, TL_{net} is the pure and TL_{BKG} is the background thermoluminescence read-out of each pellet.

2.1.5 Calibration curve

To determine the calibration coefficients (CF) and drawing the calibration curve, in this step, all the dosimeters that are intended for measurement were first annealed and then, using Co-60, Piker-V9 irradiation system of SSDL, were irradiated in the groups of 0.3, 0.5, 0.7, 0.9, 1.1, and 1.3 Gy. In order to reduce the measurement uncertainty, three TLDs were used in each radiation group and three items were considered as control dosimeters. Each group was assigned the average reading of three dosimeters, after subtracting the background radiation. After irradiation, dosimeters were read and the average data of each irradiation group were determined. As a result, the calibration curve was drawn as the dose value according to the read-out values (Aghaei Amirkhaizi and Shah Hosseini, 2019; Kohi and Hadizadeh Yazdi, 2013).

2.2 Dosimetry of photon beam, using reference ionization chamber

In order to validate the dosimetry results performed by the TLD dosimeter, the photon field of the accelerators of the selected radiotherapy centers have been conducted to dosimetry, using a 0.6 cc Farmer type ionization chamber dosimeter manufactured by PTW, Germany. It should be noted that the ion chamber has been calibrated in the laboratory of the IAEA, and measurements were also made with the ionization chamber under the same dosimetry conditions as TLD. In Fig. 2, pictures of the TLD dosimeters and the Farmer-type ionization chamber that have been used in this research, are shown.

According to TRS. 398 of IAEA (Musolino, 2001), using Eq. (4), absorbed dose of accelerator photon beam field can be determined:

$$D = M\, K_{TP}\, K_Q\, N \tag{4}$$

In this equation, D is the absorbed dose, M is the average electric charge reading in one minute, K_{TP} factor to correct the response of an ionization chamber for the effect of the difference that may exist between the standard reference temperature and pressure specified by the standards laboratory and the temperature and pressure of the chamber in the user facility under different environmental conditions, k_Q, is the beam quality correction factor and N, is the ionization chamber calibration factor.

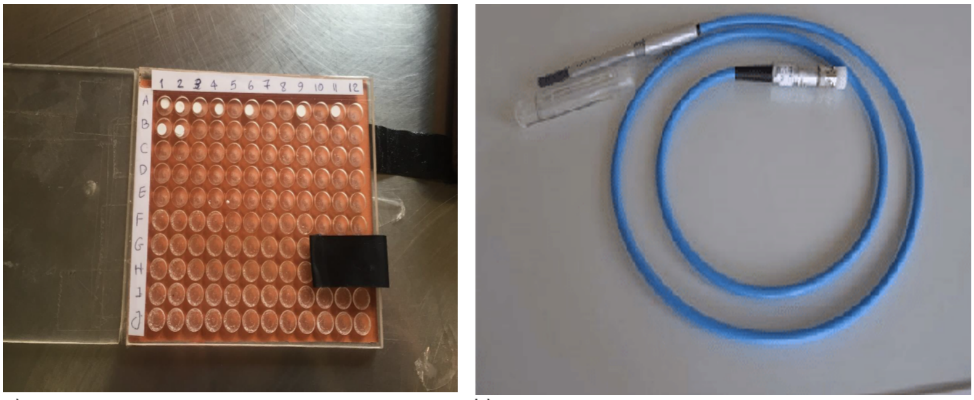
It should be noted that, the irradiation time in radiation therapy using a linear accelerator is interpreted as a quantity called monitor unit (MU), which is equivalent to 1 cGy of the deposited dose at the depth of the maximum dose in the field of 10 × 10 water phantom. In Table 2, the dose rate of the accelerators in the irradiation process have been provided as Gy/100 MU.

3 Results

According to the previously mentioned method, the Ecc values of TLD-700 dosimeters used in radiation field dosimetry of radiation therapy centers accelerators were

Table 1: The results of dosimetry performed with the Farmer ion chamber reference dosimeter for one of the accelerators in detail.

T (°C)	P (mb)	k_{TP}	k_Q	N	M (nC)	D (Gy)$_{Farmer}$	D (Gy)$_{TLD}$	Δ (%)
23.5	0.854	-0.8	0.990	51.01	14.66	0.840	0.843	-0.350



a) b)

Figure 2: Picture of a) TLD-700 dosimeters, b) PTW-Farmer ion chamber dosimeter, 0.6 cc, used in this research for dosimetry of the radiation field of hospital accelerators.

determined. Figure 3 shows the Ecc coefficients variation curve for the number of 23 used dosimeters. According to the mentioned figure, these coefficients are distributed between 0.96 and 1.06, and as expected, their distribution is close to the Gaussian function. In Fig. 4, the calibration curve related to dosimeters obtained from plotting the calibration coefficients in terms of dose values of 0.3, 0.5, 0.7, 0.9, 1.1, and 1.3 Gy is shown. As can be seen in this figure, this curve is a straight line.

Also, dosimetry of photon beam field of the accelerators has been performed using ionization chamber. For one of the accelerators the results are shown in Table 1.

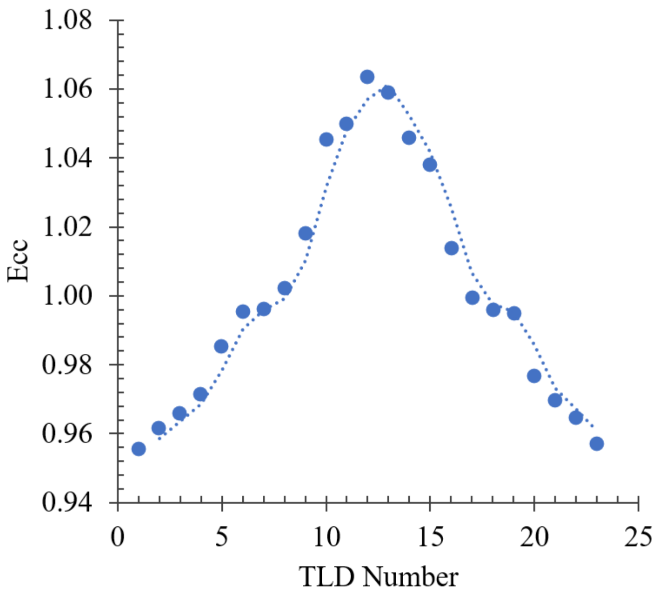


Figure 3: E_{cc} coefficient's curve for TLD-700 dosimeters which are used in this research.

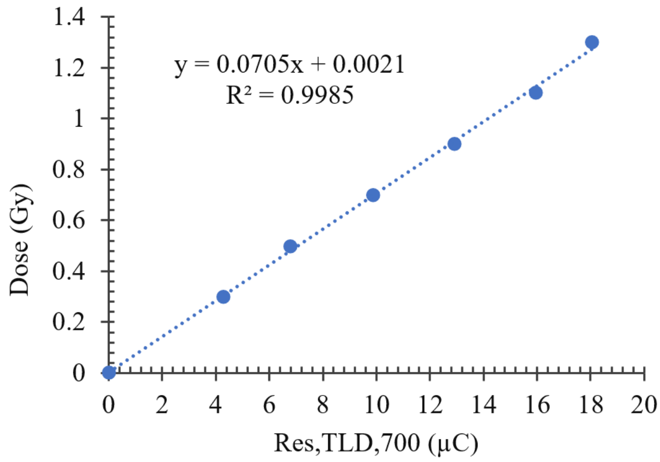


Figure 4: Calibration curve of TLD-700 dosimeters used in measuring the absorbed dose of the radiation field of therapeutic accelerators.

After drawing the calibration curve, TLD-700 dosimeters were exposed to a certain amount of radiation in five different radiation therapy centers and were read on the same date of radiation to avoid fading effect. After applying Ecc coefficients and corrections related to background dose effects, absorption dose values were determined for each radiation therapy center using the calibration curve (Table 2). Also, the absorption dose of the photon field of the selected centers has been measured using the reference dosimeter of the Farmer-type ionization chamber under the same conditions, the results of which are given in Table 2. According to the data in this table, the comparison between the measurement results with the TLD dosimeter and the Farmer type ionization chamber shows a difference between −0.35 and +1.12%. Since the uncertainty of less than 3% is acceptable in therapeutic fields, the results of this research are within an acceptable range.

Table 2: The results of dosimetry performed with the TLD dosimeter and the Farmer ion chamber reference dosimeter and their differences.

Accelerator	Measurement results with TLD (Gy)	Measurement results with Farmer (Gy)	Difference of measurement using TLD and Farmer (%)
A	0.892	0.897	0.55
B	0.876	0.886	1.12
C	0.896	0.896	0
D	0.843	0.840	-0.35
E	0.866	0.865	-0.11

4 Conclusions

The purpose of this research is the feasibility of conducting a comparative dosimetry program using the TLD dosimeters. This work was conducted in order to control the amount of dose delivered to the patients, through dosimetry of the therapeutic fields using thermoluminescence dosimeters to quality control in the radiation field calibration of radiation therapy devices. In this research, it was found that the therapeutic field dosimetry uncertainty using TLD-700 chips, compared to the ion chamber reference dosimeter calibrated in the IAEA's primary standard laboratory, is less than 1.12% and is within the acceptable range of less than 3%. As mentioned, the secondary standard laboratory (SSDL), in order to monitor radiation therapy centers, annually calibrates the radiation field of these centers using Farmer type ionization chambers.

By carrying out the comparative TLD dosimetry program, it is possible to dosimetry the radiation field of radiation therapy centers twice a year, at a distance of 6 months from each other, and with two different methods. Obviously, this will reduce the uncertainty in delivery of the prescribed dose to the patient.

Conflict of Interest

The authors declare no potential conflict of interest regarding the publication of this work.

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