Implementation of a Thermoluminescence Dosimetric Laboratory for Brazilian Brachytherapy Sources

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Abstract — **This work describes the main characteristics of the dosimetric laboratory setup for experimental brachytherapy sources dosimetry to be implemented by the Nuclear and Energy Research Institute - National Nuclear Energy Commission Sao Paulo (IPEN-CNEN/SP) and a TLD-100 dosimeters selection from a batch is also described. For the experimental dosimetric analysis, the thermoluminescence (TL) dosimetry technique was selected. It was applied TLD-100 microcube shapes dosimeters and Solid Water^{TM} phantoms water simulators to the measurements. The absorbed dose data acquisition was conducted by a Harshaw 3500 TLD and a special oven for the dosimeters thermal treatment was projected. TLD-100 batch selection was performed with a panoramic Cobalt-60 irradiator. Dosimeters batch selection was performed after irradiations in a panoramic Cobalt-60 irradiator, establishing 5.25% as the lowest standard deviation for the reproducibility of TL responses. The TL response (arbitrary units) of the all selected dosimeters was lower than 8%.**

The TLD-100 dosimeters reproducibility and others dosimetric processes and devices to acquire the source's dose distributions data were considered suitable for dosimetric studies with low dose rate brachytherapy sources.

Keywords— **Dosimetry, TLD selection, Brachytherapy.**

I. INTRODUCTION

Radioactive sources for brachytherapy application have been used since the beginning of the twentieth century for the treatment of diverse tumor sites located in different parts of the human body [1, 2].

To satisfy the Brazilian people needs, the Nuclear and Energy Research Institute - National Nuclear Energy Commission, at São Paulo city (IPEN-CNEN/SP), started the research and development of radioactive sources fabrication applied to brachytherapy [3,4]. For this purpose, IPEN-CNEN/SP started the production and research with a widespread low dose rate brachytherapy source, iodine-125 (^{125}I) seed [5]. In Brazil, the majority procedures with ^{125}I seeds are concentrated in permanent prostate implants and for temporary ocular plaque applications [2,4]. With a national production, the radioactive sources costs will reduce and consequently it will increase the treatment access for patients with low income.

During the research, development and for quality control there was a necessity of the establishment of a dedicated laboratory to analyze and conduct the experimental dosimetric aspects concerning the sources used in brachytherapy. This laboratory must be able to determine some dosimetric parameters used in dose distribution of treatment planning systems and to perform a quality control of the produced sources. For these purposes, a laboratory was created to perform the dosimetry research concerning the brachytherapy sources [6].

The chosen equipments and the main procedures developed for this laboratory are described and analyzed in this work. Thermoluminescence (TL) was the technique selected to verify the dosimetry of the Brazilian brachytherapy sources, due to its broad utilization for decades on research and specific applications in radio-therapeutic equipment and sources, including brachytherapy [7].

II. MATERIALS AND METHODS

A. Dosimeters and Irradiation Conditions

It was chosen the TLD composed by LiF:Mg,Ti, known commercially as TLD-100, due to its very established behavior during decades of use worldwide. This dosimeter is found in several shapes and dimensions, has dose linearity up to 1 Gy, effective atomic number equal to 8.2, which is near human tissue that is 7.4, besides having TL peak emissions relatively stable, since these TL peaks fading is insignificant [8-10]. These are the main factors for choosing TLD-100 as the dosimeter to be used for brachytherapy sources.

The TLD-100 model used in the laboratory is the TLD-100 microcube, a cubic-shaped with 1 mm^3 volume, dimension that allows the dosimeters to be adequate for any region in the phantom water simulator, close to a punctual dose and without major fluency interference on the other dosimeters.

These TLD-100 characteristics are in good agreement with the American Association of Physics in Medicine (AAPM) formalism Task Group No. 43 recommendations for experimental dosimeters [7, 11]. The methodology that will be used for the IPEN-CNEN/SP dosimetric laboratory to obtain the absorbed dose rate values, around the brachytherapy sources, is well described elsewhere [7, 11-14].

This selection of TLD's was conducted from successive dosimeters irradiations in a panoramic Cobalt-60 irradiator model Fis60-04 with a 15.74 TBq (during the dosimeters selection) situated in the Radiation Technology Center - IPEN-CNEN/SP. For establishment of specific dosimetry factors, it was performed irradiations with the brachytherapy source in the center of the phantom.

The support or Phantom, where source and dosimeters are placed, composed of a material equivalent to water, was employed during the irradiation with the irradiator, for dosimetry selection, and it will be employ with the brachytherapy source irradiation, for quality control and dose rate calculations. The dosimetric laboratory uses phantoms of the type Solid Water^{TM}, model RW1 (PTW - Freiburg, Germany), measuring 30 x 30 x 2 cm and composed of a white polyethylene matrix with magnesium oxide and calcium carbonate [15]. The main aspect of Solid Water^{TM} RW1 phantom can be considered the indication for low energy photons dosimetry, lower than 100 keV, as low dose rate (LDR) brachytherapy sources [7,16]. Figure 1 illustrates the phantom specially developed to hold TLD-100 microcube dosimeters around the ^{125}I brachytherapy source.

To provide radiation backscattering during dosimeters irradiation, other phantoms must be positioned above and below the main phantom where the brachytherapy source and the dosimeters are positioned [16]. For the Cobalt-60 irradiations, two Solid Water^{TM} RW1 phantoms were used to provide charged particles equilibrium conditions and every hole were filled with TLD-100 dosimeters.

B. TLD Reading Process

Manual Harshaw model 3500 (Thermo Fisher Scientific – Waltham - USA) was adopted due to its excellent reproducibility for different dose levels [17, 18]. This reader heats the dosimeter by an ohmic contact (planchet); when heated, the TL response is released and captured by a photomultiplier, which exports the TL signals to a microcomputer through software, recording the values measured.

The software used by the reader, WinREMS^{TM} (Thermo Fisher Scientific – Waltham - USA) records the exit parameters in ASCII characters; at moment, this software presents the integrated value of TL measurements, i.e., it is not possible to have the obtained value, for each acquisition channel of TL reader data, registered.

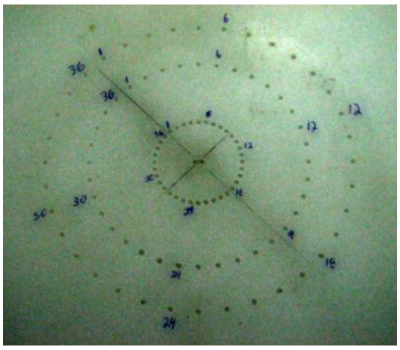

Fig. 1 - Solid Water^{TM} phantom used during Cobalt-60 irradiations of dosimeters for selection and for future brachytherapy source irradiation, in dosimetric analysis.

Due to the photomultiplier sensitivity to the electric grid tension, the dosimetric laboratory has a stabilizer that, connected to the TL reader, minimizes the tension variations and reduces the photomultiplier "electronic noise", which may influence the TL readings, during the electrical charge accumulation.

Additionally, the TL reader employs pure nitrogen (99.9995%), during the measurements, to reduce the oxygen gas effects along the TL results acquisition and minimize the oxidation effects on dosimeters and apparatus components [17]. The reader allows the achievement of heating rates ranging from 1 ^{o}C.s^{-1} to 50 ^{o}C.s^{-1} and reaching a maximum temperature of 400 ^{o}C; this broad range allows the research with other possible TL materials, besides exploring different ways for the TL response acquisition.

To avoid uncertainties in the TL reading process, about 20 h are waited for the unstable peaks decay of the TLD; a pre read thermal treatment for 10 or 15 minutes may be employed instead of 20 h of "delay" time, but the TL reader has pre-heating phases. Therefore, it is possible to heat the dosimeter to the value required by the user, without the storage of these values by the software in the final contribution of the dosimeter response [6, 8]. As these peaks have activation energies lower than the dosimetric interest peaks, the pre-heating will not affect the main TL peaks responses. The reader also allows making the dosimeters post-heating; after the data acquisition, it is possible to heat the dosimeter "to clean" the remaining thermoluminescent information and use it for the next irradiations, without thermal treatment.

The alterations of all useful parameters to obtain TL measurements are made by the WinREMS^{TM} software. The brachytherapy laboratory protocol uses the following values, for a TLD-100 microcube: pre-heating up to 50 ^{o}C, without data acquisition; data acquisition from 51 ^{o}C up to 260 ^{o}C with a linear heating rate of 10 ^{o}C.s^{-1}.

Today, in the dosimetric laboratory, the TL dosimeters post-heating is not necessary, since the read dosimeters are submitted to the conventional thermal treatment (400 ^{o}C for 1 hour and 100 ^{o}C for 2 hours), just after data acquisition.

C. TLD Thermal Treatment

It is necessary that a TL material undergo a thermal treatment to return for its stable state before new irradiation or reuse purposes, even after TL reading acquisition. Thus, the thermal treatment avoids that traps and other metastable states may still release TL signals, already measured [19]. There are several manners and methodologies for the TLD-100 thermal treatment [20]. The brachytherapy laboratory sources choose the 400 ^{o}C for 1 hour, with a constant cooling gradient near 4 ^{o}C.min^{-1} (slow cooling rate) and later, 100 ^{o}C for 2 hours.

The dosimetric laboratory acquired a special furnace for the thermal treatment described above; the furnace is constituted of a stainless steel cylinder that allows the dosimeters supports accommodation. This furnace has a coupled cooler that automatically performs the cooling gradient without TLD microcubes manipulation or furnace shift; reducing temperature uncertainties and avoiding very high temperature gradients that can damage the crystal structure of the TLD. Inside this cylinder, there is a temperature sensor (thermocouple type K), with measurement uncertainty near 1.7 ^{o}C, verified by a certified metrology laboratory. The TLD-100 microcubes are placed in a pure aluminum tray with labeled individual cavities.

D. TLD Selection

The dosimeters chosen to perform the dosimetric analysis were selected from a batch with 203 dosimeters.

For an accurate dosimetric analysis with LDR brachytherapy sources, using TL dosimetry, a TLD-100 selection from a batch is important to guarantee that the selected dosimeters present the higher reproducibility and repeatability from the whole batch dosimeters acquired.

The dosimetric laboratory estimates that 80 TLD-100 dosimeters will be used in the further dosimetric analysis with LDR brachytherapy sources, this estimative value were considered from previous studies and “on job” experience [6].

The dosimeters with poor shape regularity in your faces were excluded from the selection analysis. This inspection was realized with none optical device or special instrument and just by the operator visual inspection. Our visual inspection found 3 dosimeters with irregular shapes formats and they were excluded from the TLD-100 selection with a Cobalt-60 irradiator [18].

The irradiations occurred in a Solid Water^{TM} phantom in a vertical position parallel to the irradiation beam, each dosimeter has a fixed position in the phantom to avoid high uncertainties caused by TLD-100 sensitivities. Solid Water^{TM} phantom with the TLD-100 positioned and other phantom for the adequate charged particle equilibrium, were submitted to four series of irradiation with 60 cGy, under identical reading, thermal treatment and storage conditions previously cited that will be used for LDR brachytherapy sources. The dose value (60 cGy), beyond the dosimeter linearity, is the more adequate and reasonable value to perform the irradiations in the Cobalt-60 irradiator, due to position of the phantoms (maximum distance) and time of irradiation (high uncertainties in short irradiations duration).

III. Results and discussions

All analysis in the Cobalt-60 irradiator was conducted using the systems and procedures previously mentioned, this dosimeters selection is a verification of these procedures, i.e. any abnormality on the process will be indicate in the homogeneity of the obtained results.

After four irradiation cycles with the Cobalt-60 irradiator, the standard deviation from each dosimeter was obtained. Dosimeters with the lower standard deviation values from the four Cobalt-60 irradiation series were selected.

To simplify the analysis, equation 1 was used to express the deviation, in terms of percentage:

$$Deviation(\%) = \frac{\sigma}{M} \cdot 100 \qquad (1)$$

Where:

σ: Standard Deviation of the four irradiations;

M: Arithmetic Mean of the four irradiations.

Those dosimeters that obtained relative deviations higher than 5.2% were eliminated rendering 81 dosimeters selected. Figure 2 shows a histogram that represents the deviations of 81 TLD-100 using equation 1. Approximately 83 % from the selected dosimeters of the dosimeters range values, between 4.25 and 5.25 % of deviation.

In the series of Cobalt-60 irradiations, the dosimeters showed to be stable and reproductible concerning TL response. The standard deviation of the all selected dosimeters response arithmetic mean (in random units) was lower than 8 %. Some considerations must be related, the Cobalt-60 irradiator used for the TLD-100 selection is more applied in irradiations process with high doses (> kGy); to delivered 60 cGy (positioned in the Cobalt-60 irradiator maximum distance) a short time of irradiation (< 60 sec.) will increase the uncertainty of the absorbed dose in the dosimeters. This TLD-100 selection methodology is not the only possible to selected the dosimeters. Others selection methodologies, e.g. as the method suggested by the International Electrotechnical Commission (IEC) [22].

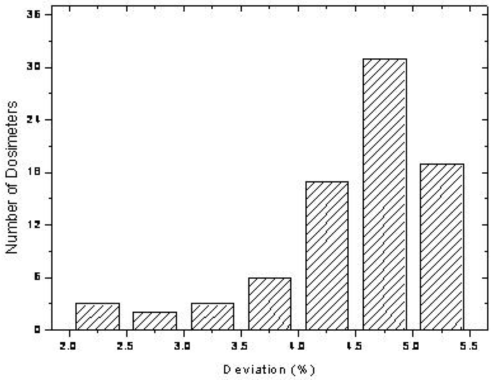

Fig. 2 - Histogram of the selected dosimeters to be used in brachytherapy sources dosimetric analysis.

The IEC method was not used because it is based on the maximum and minimum dosimeters responses (sensibility) inside a batch. This method is convenient for a group of dosimeters with the same calibration factor and not for dosimeters with individual calibration factors.

IV. Conclusions

The IPEN-CNEN/SP brachytherapy dosimetric laboratory shows to be ready for the practice of diverse TL assays intended for brachytherapy sources. The basic dosimetric systems meet the major recommendations for experimental dosimetric analyses. In principle, the brachytherapy sources that may be conveniently researched in the laboratory are those with a low dose rate brachytherapy sources.

In the dosimeters selection, the TL systems (thermal treatments and TLD data acquisition) were considered suitable to perform the several dosimetric analysis recommend by the dosimetric protocols for brachytherapy sources. The selected dosimeters have maximum deviation of 5.25 % showing good batch homogeneity.

For future comparisons with other dosimetry systems, the dosimetric laboratory is intended to utilize results obtained from computerized simulations for comparisons and verification of the brachytherapy sources parameters.

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