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Calibration of a Clinical Beta Therapy Applicator using the Thermoluminescence Samples: Preliminary results

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Abstract. In some parts of Brazil, 90Sr/90Y clinical applicators are still used for dermatological and ophthalmic treatments, even with the higher efficiency of linear accelerators because they are of lower cost and easier use. Calibration and periodic recalibration of these applicators to verify the absorbed dose rate is essential to ensure accuracy in clinical treatments. In this work the thermoluminescent response of BeO and μLiF pellets was evaluated, determining the reproducibility, linearity of response and their dose-response curves. This standard, for this type of calibration, recommends the use of small detectors such as μLiF. Therefore, the utility of μLiF and BeO in the calibration of clinical applicators was compared.

Key words. Beta radiation, clinical beta therapy applicators, beta therapy, dosimetry.

1. Introduction

The Brazilian health system, as a whole, presents some lacks in manpower and infrastructure. In the radiotherapy area it is not different, the lack of linear accelerators, instigates the search for alternatives that may replace this kind of instruments. Beta therapy is one of these alternatives that the Brazilian Unified Health System and private services still use to supply the demand.

The 90Sr/90Y clinical applicators with a half-life of 28.8 years are still used for dermatological and ophthalmic treatments [1]. Calibration and periodic recalibration of these applicators, to verify the absorbed dose rates, are essential procedures for the quality assurance in clinical treatments [2], and one of the known techniques for this procedure is the dosimetry based on the thermoluminescence phenomenon.

The field of thermoluminescent (TL) dosimetry has been expanding since the 1960s, with major publications involving appropriate materials for personal dosimetry. In the same decade, research focused on the thermoluminescence of beryllium oxide (BeO) and lithium fluoride (LiF).

Beryllium ceramics exhibit not only high thermal conductivity, but also a unique combination of other chemical properties such as high chemical and thermal resistance, considerable specific volumetric resistance and low dielectric losses [3, 4]. Its effective atomic number (Z ~ 7,22) is very close to the effective atomic number of biological tissue (Z ~ 7,6), providing research in radiation metrology in the areas of diagnostic radiology and radiotherapy [5, 6].

LiF is well known for having unique optical properties. Its dispersion in the visible region of the spectrum is low and transmits more in the ultraviolet region than any other known substance. As is not

the case in nature, it is necessary to synthesize the compound and crystallize it from the molten material in the laboratory. Its dosimetric applications are very well known and used in radioprotection and medicine. LiF: Mg, Cu, P and LiF: Mg, Ti detectors are some of the most popular thermoluminescent dosimetry materials for personal, environmental and clinical dosimetry due to their high sensitivity and equivalence to human tissue [7, 8].

Thermoluminescence is the thermally stimulated emission of light following the previous absorption of energy from radiation [9, 10]. If the materials are associated with a transducer, the emitted light signal is transformed into an electrical signal. In this way, it is possible to measure, proportionally, the dose that was initially deposited on the TL materials.

Radiotherapeutic procedures in dermal beta therapy, ophthalmological beta therapy and beta therapy for pterygium prophylaxis are formalized in the Unified Health System [11]. These procedures are intended to prevent and treat the formation of keloids, small malignant neoplasms of the skin and cases of pterygium. In NN 3.01 it is informed that holders of clinical services, private or public, should ensure the calibration of equipment and sources for clinical dosimetry, with supervision of experts qualified by the Brazilian Nuclear Energy Commission [12].

The objective of this work was to compare the thermoluminescent responses of BeO and LiF samples in the calibration of beta therapy clinical applicators based on the international standard ISO 21439 (2009) [2].

2. Materials and Methods

2.1. Dosimetric samples

Beryllium oxide pellets with a volume of 40.2 mm^3, 99.0% BeO, with 1% remaining elements such as Si, K and Al were used, and LiF-type samples were also used: Mg, Ti (µLiF), cubic format with dimensions of 1 mm. These samples were dosimetrically characterized. In addition, the mass measurement of these samples was performed for the possible need for correction to the obtained data.

2.2. Radiation systems

Two radiation systems were used to characterize the dosimetric material. The first is part of a RISÖ reader system, Risö TL / OSL-DA-200 model, with a dose rate of 83 mGy s^{-1}. The second is a source from the 90Sr/90Y BSS2 secondary standard system with a dose rate of 119 µGy s^{-1} (2005/04/27), Amersham Buchler, calibrated in the German Primary Standardization Laboratory, Physikalisch-Technische Bundesanstalt (PTB), at the distance of 11 cm The BSS2 system presents in its certificate the air dose rate and skin dose rate correction factor.

2.3. Reader system

Two TL reader systems were used, Harshaw Nuclear Systems, model 3500A/B, with a heating rate of 10 ° C / s and constant N_2 flow of 5.01 / min for BeO and the RISÖ model TL / OSL-DA-20, with a heating rate of 0.1 °C/s to 10 °C/s, it way reach a temperature of 700 ° C for the µLiF TL reading.

2.4. Heat treatment for sample reuse

After irradiation, it is always necessary to disarm the remaining electrons. The samples were subjected to heat treatment. A Vulcan 3-550PD muffle furnace with a heating rate of 40 °C/min was used and the BeO dosimetric material was treated at 500 °C for 15 minutes. µLiF was treated at 400 °C during 1h and 100 °C during 2h.

2.5. Clinical Applicator Calibration

The Calibration Laboratory of Radiation Metrology Center at IPEN has a retangular dermatological clinical applicator with manufacturer calibration certificate, with 1 cm x 2 cm nominal active area. The

calibration procedure of clinical applicators using luminescent materials, based on the recommendations described by the international standard [13].

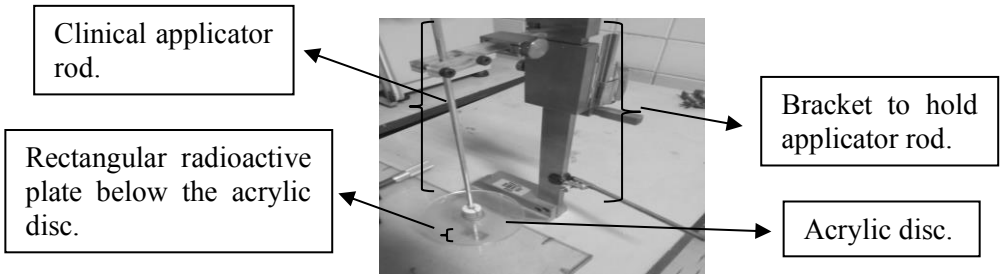

Figure 1. *Clinical applicator adjustment rod positioned 1 mm from dosimetric sample.*

2.6. Uncertainty

Following the normative document [13], the uncertainty analysis was performed considering type A, statistical uncertainties related to measurements, and type B uncertainties that are related to equipment performance. This work maintained a 95% confidence level as expected by the standard.

$$\sigma^2_{total} = \sigma^2_A + \sigma^2_B \qquad \text{Equation 1.}$$

where σ^2_A are the statistical uncertainties and σ^2_B are the systematical uncertainties.

2.7. Dosimeter characterization

The samples were characterized according to the following tests: response reproducibility, response linearity, sample batch homogeneity and dose response curves. For all tests, several measurement and heat treatment cycles were performed.

2.8. Recommendations for the calibration of Clinical Applicators

Key documents involving brachytherapy sources state that a clinical applicator calibration should be in accordance with the dose rate deposited on tissue or water. Each dosimeter should not exceed a 5% uncertainty margin (k = 1) within the response reproducibility. Dosimeters should be calibrated in relation to a standard primary or secondary radioactive material. Calibrations should cover the total area of the flat or concave plate; the source-detector reference distance should be 1 mm, the dosimetric sample should be positioned on the center axis of the clinical applicator, and it is recommended to use sample sizes of maximum 1 mm [2].

3. Results

Forty-six BeO samples and twenty µLiF samples were tested and, before classifying them for their dosimetric properties, the most appropriate thermoluminescence responses were defined. Reproducibility was determined in 6 or 10 cycles of 1Gy dose measurements, surface dose rate in air for reproducibility with RISÖ reader system, where the mean value, standard deviation and coefficients of variation (CV) value were calculated [7].

For all measurements, the background radiation values were initially determined. Measurements were normalized by the ratio of the mean background counts to the background count value at the time of each measurement. In addition, measurements were normalized to the values obtained without irradiation of each sample (for non-irradiated sample) and normalized by the ratio of the average dosimeter masses to the mass of each dosimeter.

3.1. Sample sensitivity

The sensitivity of the samples and the best response reproducibility were also determined. For this, Equation 2 was used, where M_{TL} is the TL measurement, D is the absorbed dose, m is the sample mass and f 'is the sensitivity of the sample [7]:

$$f' = \frac{M_{TL}}{mD}\left[\frac{System\ unit}{g\ .Gy}\right] \qquad \text{Equation 2.}$$

3.2 Sample selection from BeO to TL

Through Equation 2 it was possible to identify the samples with higher TL sensitivity. The mean TL response sensitivity values for the 1 Gy dose among 6 BeO samples was 5.7 $C.g^{-1}Gy^{-1}$ (± 9.4%). Table 1 shows the values obtained for the reproducibility test of the 6 best BeO pellets.

Figure 2 shows the TL curve of a BeO sample.

Table 1. *TL measurements and related type A uncertainties for 6 measurement cycles of BeO samples.*

Sample	Mean Value (M) (C)	Standard Deviation (C)	σ_A (%)	σ/M (%)
1	2.76	0.04	1.6	0.6
2	3.29	0.06	2.4	0.8
3	2.96	0.06	2.4	0.8
4	4.10	0.12	4.8	1.2
5	4.82	0.12	4.8	1.1
6	3.71	0.11	4.5	1.2

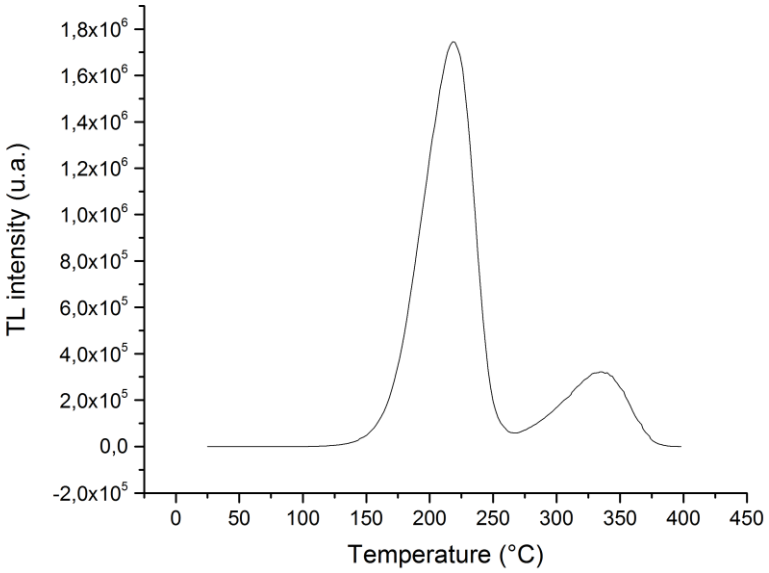

Figure 2. *TL emission curve of a BeO sample, irradiated with 1 Gy of beta radiation.*

The TL curves showed the main peak between 200°C and 210°C and the secondary peak around 350°C; and the curves represent signals collected after 48 h of irradiation, with 10% decay of the initial

signal, remaining stable for another 3 months [9, 10, 15]. The values obtained in these measurements to investigate reproducibility are within the recommended values for uncertainties and variation coefficients [2, 7]. The maximum value obtained was 4.8% for uncertainties and 1.2% for CV.

3.3 Sample selection of µLiF for TL

Five pellets with excellent reproducibility were selected to obtain the dose response curve. The mean TL response sensitivity values for the 1 Gy dose among the 5 µLiF samples was 580.1 u.a. $mg^{-1}Gy^{-1}$ (± 6.8%). Table 2 shows the statistical uncertainties of the TL response of these samples.

Figure 3 shows the TL curve of a µLiF sample.

Table 2. *TL measurements and related uncertainties for 6 measurement cycles of µLiF samples.*

Sample	Mean Value (M) (u.a.)	Standard Deviation (u.a.)	σ_A (%)	σ/M (%)
1	2.75	0.09	3.7	1.3
2	2.45	0.11	4.5	1.8
3	2.33	0.08	3.3	1.4
4	2.34	0.11	4.5	1.9
5	2.46	0.09	3.7	1.5

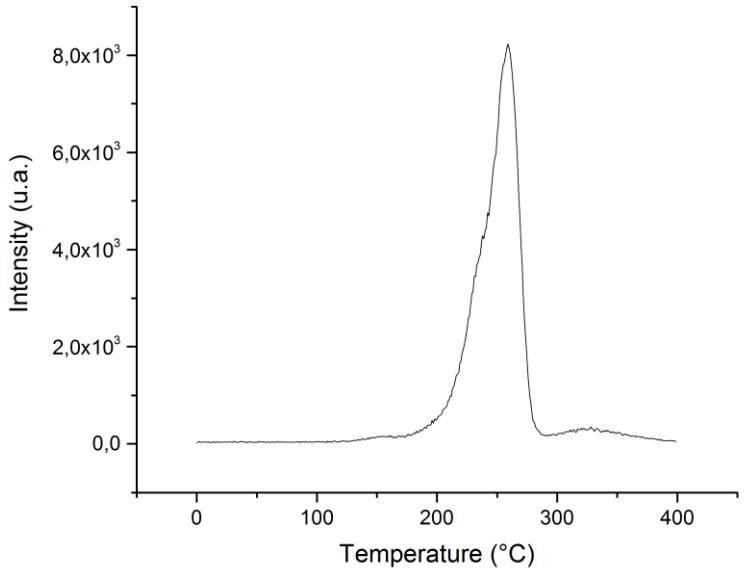

Figure 3. *TL emission curve of a µLiF sample, irradiated with 1 Gy of beta radiation.*

The µLiF TL curves showed the main peak around 260ºC and the curves represent signals collected after 24 h of irradiation, with a decay of up to 3% of the initial signal, remaining stable for another 3

months [10]. The values obtained in these are within the recommended values for uncertainties [2]. The maximum value obtained was 4.5% for uncertainties and 1.9% for CV.

3.4 Homogeneity

For the homogeneity test of the TL responses of the BeO dosimetric materials, the pellets approved in the reproducibility test were used and only those with a response variation of less than 20% were selected. The μLiF samples showed less than 5% variation [9, 10].

3.5 Linearity and dose response curve

Linearity and dose response curves were obtained over a dose range of 0.5 Gy to 4 Gy using the secondary standard BSS2 system at a distance of 11 cm from the 90Sr/90Y radioactive source. This range covers the dose of 2.5 Gy, the average value that is used clinically [13].

The values obtained for the linear correlation coefficient of each line adjustment were remained around 0.998. The R^2 values of the linear fit of the BeO samples ranged from 0.9992 to 0.9999, while the R^2 values for the μLiF samples ranged from 0.9974 to 0.9998. The calibration factors are shown in Table 3 and Table 4.

Table 3. *Calibration coefficients for BeO samples with the best dosimetric characteristics for TL response*

Sample	**Calibration factor F_c (Gy/ u.a.)**
1	0.362 ±0.01
2	0.304 ±0.01
3	0.348 ±0.02
4	0.244 ±0.02
5	0.210 ±0.03
6	0.270 ±0.03

Table 4. *Calibration coefficients for µLiF samples with the best dosimetric characteristics for TL response*

Sample	Calibration factor F_c (Gy/ C)
1	0.364 ±0.02
2	0.408 ±0.03
3	0.430 ±0.01
4	0.427 ±0.04
5	0.406 ±0.02

3.6. Amersham dermatological applicator calibration / SIQ21

One of the LCI clinical applicators with a surface absorved dose in air at its calibration certificate (0.024 Gy s^{-1} without uncertainty) was used. The recalibration of this applicator was performed at 1 mm distance, using the TL technique, with BeO and µLiF samples. Table 5 presents the obtained values.

Table 5. *Amersham / SIQ21 applicator calibration by BeO and µLiF samples at a distance of 1 mm. Average value of pellet measurements. For 3 measurements of 3 samples of each material.*

Sample	Surface skin dose rate (Gy/s)	Expanded uncertainity (k=2) (%)	Δ (%)
BeO	0.020	15.4	21
LiF	0.017	13.7	29

Δ: Difference between the obtained value and of the certificate value

Calibration values differed by 21% and 29% from the 1986 manufacturer's certificate value. Despite the difference, previous studies report larger differences, then those, reaching values near of 40%. The uncertainties are as expected by the standard, which states that clinical treatment uncertainty assumes a value of up to 20% [2].

4. Conclusions

BeO samples have larger dimensions than these recommended by the standard, which may explain the higher dose rate obtained in the applicator calibration for these samples compared to the value obtained for µLiF samples. Smaller material dimensions minimize uncertainties generated by clinical applicator plate asymmetry [2]. Despite the differences between the manufacturer's certificate value and those

obtained in this paper, the differences presented in other works in the literature are large, within a range of 20% to 40% [2, 15, 16]. This difference may be related to the calibration method at decades ago. Thus, both materials were useful for this purpose, and they will be used for the clinical applicators.

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