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IMPROVEMENT OF THE QUALITY CONTROL PROGRAMME OF THE CLINICAL DOSIMETERS CALIBRATION LABORATORY OF THE IPEN/CNEN-SP

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ABSTRACT

A set of clinical dosimeters (thimble ionization chamber coupled to an electrometer) commonly used in radiotherapy in Brazil and sent to the Calibration Laboratory of IPEN were under several tests and analys is parameters for the dosimeters behaviour were established, specifying their sensitivities and operating characteristics. Applied tests were: repeatability, reproducibility and current leakage. Thus it was possible to determine the most common defects found in these equipments and the actions that could be taken to prevent it (clinical dosimeters quality control programs). The behaviour of 167 dosimeters was analyzed and in this study, 62 of them have been tested. The main problem detected during calibration tests was current leakage, i.e. electronic noise. The tests were applied to the routine measurements at the Calibration Laboratory implementing an ideal calibration procedure. New calibration criteria were established following international recommendations. Therefore, it was made the improvement of the quality control programme of the clinical dosimeters calibration laboratory, benefiting the users of such equipment with better consistent calibration measurements.

1. INTRODUCTION

The Instruments Calibration Lab (LCI) performs, for over 20 years, the calibration of instruments [1-7], which are used in radioprotection measures, radiodiagnosis and radiotheraphy. This service is offered to hospitals, industries, clinics, universities and other users all around Brazil. The LCI is part of the Gerência de Metrologia das Radiações (GMR), from the Instituto de Pesquisas Energéticas e Nucleares, associated to USP and managed by the Comissão Nacional de Energia Nuclear (IPEN/CNEN-SP).

The increase on the number of clinics and hospitals in Brazil, which offer radiotherapy services helped, also, to increase the necessity for dosimetry in radiotherapy equipments. Therefore, the need to develop new projects in order to improve the lab calibration equipments (in search for agility in the results). The use of internationally known methods for calibration make it possible to obtain better results and in less time than before.

When it comes to radio therapy, the LCI has an ionization chamber, electrometer and cables triaxial to connect the chambers, and also a teletherapy system, with ^{60}Co.

The system mentioned above is used for stabilishing and controling the amount of gamma radiation beam that calibrates the clinical dosimeter, in which are used as a reference the greatness "absorbed dose to water”, Dw [2].

The control of quality well performed during the process enables the performance of safer rehearsals and (reliability) of results. Therefore, the quality system of the lab is essential if you want to obtain faster results in everything that is performed there, along with a high security level and the data obtained to inform IPEN’s clients, being mandatory the constant update of this system to increase the user’s safety while using the clinical dosimeter

The protocol of the International Atomic Energy Agency – “Calibration of Reference Dosimeters for External Beam Radiotherapy, (2009)” (Technical Reports Series N^{o}. 469), states that:

Traceability, precision and consistency on the radiation measures are essential during measuring radiation, especially in radiotherapy, when the treatment results depend mostly on the radiation dose applied to the patients.

Hence, the quality of the radiation dose applied to the patient during the radiotherapy treatment is connected to the control of the clinical dosimeter used in the system, which is directly related to the additional tests [1-6] performed by the user and to the calibration of the clinical dosimeter. Therefore, the importance of updating the system of calibration in order to have a precise dose of radiation during radiotherapy procedures.

2. OBJECTIVE

The objectives of this work were:

- Improve the quality already shown at the Laboratório de Calibração de Dosímetros Clínicos de Radioterapia from IPEN/CNEN-SP, making it suitable to the new protocol of the IAEA - Calibration of Reference Dosimeters for External Beam Radiotherapy, (2009)” (Technical Reports Series N^{o}. 469) , which is a new update to the “Calibration of Dosimeters Used in Radiotherapy, (1994)” (Technical Reports Series N^{o}. 374) e “Absorved Dose Determination in External Beam Radiotherapy, (2000)” (An International code of practice: Technical Reports Series No. 398) , which is also an update to the protocol “Absorbed Dose Determination in Photon and Electron Beams, (1987)”, (An International code of practice: Technical Reports Series N^{o}. 277).
- Conduct a study on how different models of clinical dosimeter used to calibrate at the LCI work, updating the archive of calibration to each model and manufacturer of the clinical dosimeter.
- Study the leakage current test in clinical dosimeters to be calibrated and verified to make sure mistakes that often happen in the lab won’t occur.
- To study the reproductibility of the clinical dosimeters, especially the ones used at IPEN for quality control, to analyse how it works along with the radiator.

3. MATERIALS E METHODS

The main equipments used in this research were the clinical dosimeters composed by ionization chambers, wires and "conectores triaxial" and eletrometer with high power capacity sent by clients to be calibrated by the laboratory, and also the standard clinic dosimeter from the LCI composed by an ionization chamber Nuclear Enterprise 2505/3, wire and adaptor Nuclear Enterprise, eletrometer PTW Unidos 10002; as seen in Fig. 1.

Figure 1: Standard clinical dosimeter of LCI:
(a) eletrometer. (b) cable. (c) conector. (d) ionization chamber.

Tab. 1 shows the models and manufactures of the clinic dosimeters used in this research

The measure scale was corrected for the temperature reference (20.0±0.1) ^{o}C, pression (101.3±0.1) kPa and relative humidity of the air around 50%.

Table 1: Clinic material analyzed

Clinical Group Manufacturers
NE
Exradin A12
Wellhofer
PTW
SNC
IBA
INOVISION
Victoreen
SNN

3.1 Radiation Systems and Sources

It was used an teletherapy irradiator Siemens, model Gamatron of ^{60}Co, with activity 0.34TBq at the reference date 1999 (precision de ±5%) e ^{60}Co performs two gamma ray emission energy 1.17 e 1.33 MeV.

3.2 Auxiliary Systems

Were used as auxiliary systems:

- Computer HP, model PC Pentium 4.
- Thermometer Incotherm, mercury, with measuring range from –10 and +40°C and precision ±5%.
- Barometer Veränderlich, model Domatic, Germany, with measuring range between 96 e 104 kPa e precision de 0.1 kPa.
- Hygrometer Präzision-Faden, Germany, with measuring range between 0 and 100% and precision of 1% relative humidity.
- *Phantom* of acrylic, dimensions 30x30x30 cm.
- *Holder*`s of acrylic.
- Table for support and positioning.
- Lasers for positioning model Lumina-L2.

The temperature and relative humidity in the laboratory were controlled with air-conditioners and dehumidifiers.

3.3 Methodology used for calibrating the clinic dosimeters

The tests performed during the calibration of the clinic dosimeters consist in reading the source of gamma radiation, ^{60}Co, with pre established values its half-life from the standard clinic dosimeter from the Lab. To do so, it was used all the measures mentioned before, as correcting the temperature and pressure, simultaneously with the temperature and pressure of the air.

Controlling these parameters, you can obtain ideal conditions to perform the needed measures to verify the state of the ionization chamber, extension wire, connectors, electrometer and determine the reference value, which in this case it is the dose of water absorbed, D_w. To obtain the D_w. it is used the calibration coefficient, factor $N_{D,w}$, given by the laboratory (in this experiment, the clinic dosimeter from the LCI had a calibration factor made by the Physikalisch Techinische Bundesanstal – PTB (primary lab).

Fig. 2 and 3 show the calibration rehearsals of the clinic dosimeters performed in the LCI Bunker.

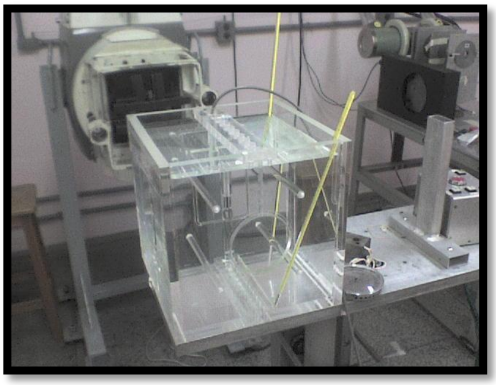

Figure 2: Arrangement for calibrating dosimeters clinicians. System of teletherapy irradiator Siemens, model Gamatron, with radiation source range ^{60}Co, ionization chamber Nuclear Enterprise (NE), *phantom* with thermometers to measure the temperature of the distilled water and hygrometers to measure the relative humidity of the place.

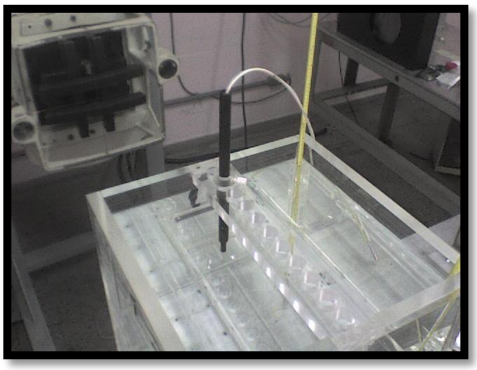

Figure 3. Demonstration of calibration dosimeters clinical ionization chamber Exradin A12 (which is waterproof and uses another holder for fixation).

4. RESULTS AND ANALYSIS

4.1 Studies of the calibration factors $N_{D,w}$

To analyze the calibration factors for each clinic dosimeter manufacturer it was used the calibration archive of the LCI. This archive (with $N_{D,}$w values) was updated during the time this research was performed. Therefore, to create a model/manufacturer group and determine an average statistical value for the calibration system corresponding to each group, it was analyzed only clinical dosimeter from the same model/manufacturer.

Table 2 show the amount of equipments analyzed in the calibrations performed by the LCI,the average of $N_{D,w}$ factors (clinic each set, the standard deviation and the average final uncertainty [in this case we used the standard deviation as uncertainty type "a" and, with type "b" we used the factor of uncertainty in the calibration certificate supplied (±1.5%)]. Fig. 4 show the $N_{D,w}$ values for each clinic dosimeter calibrated with each manufacturer/model and the statistical fluctuation for each model.

Table 2: Data from calibration factor, $N_{d,w}$, for ionization chamber model.

Ionization Chamber	$N_{D,w}$ Average		Uncertainty	
Victoreen 580	54.1102	±	1.5144	mGy/ue
Wellhöfer-IBA	48.0771	±	1.5050	mGy/ue
NE 2505/3B	46.1600	±	1.5116	mGy/ue
PTW TN30013	53.5561	±	1.5015	mGy/ue
PTW TN3001	53.6179	±	1.5101	mGy/ue
Exradin A12 Ns: Only Number	49.3949	±	1.5155	mGy/ue
Exradin A12 Ns: XA	48.4902	±	1.5077	mGy/ue

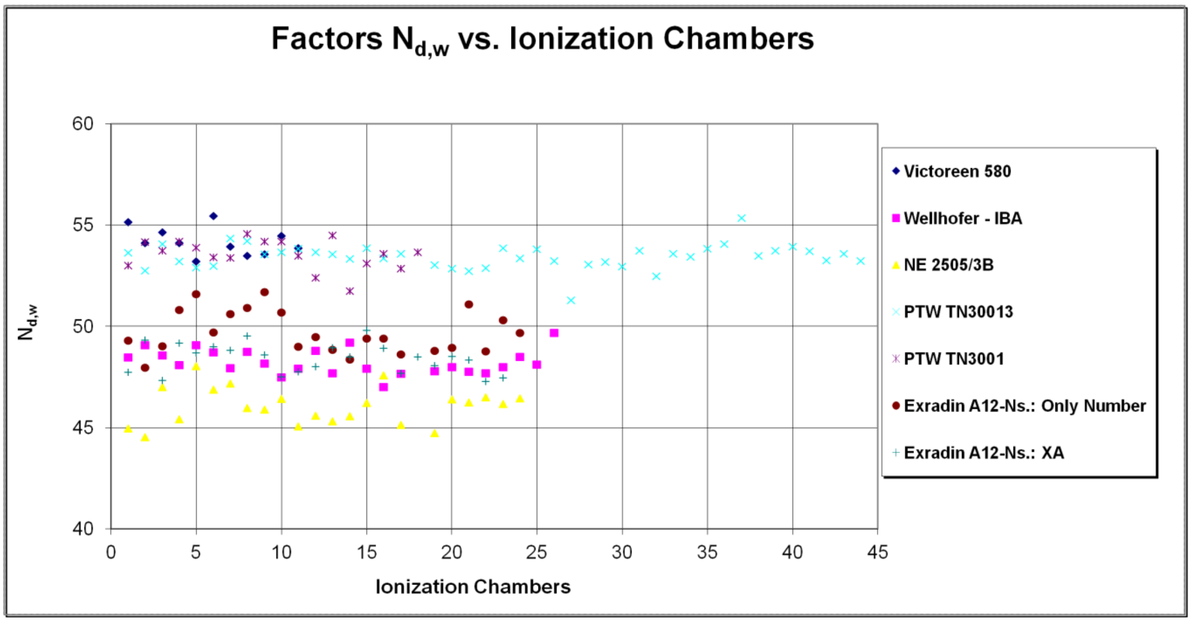

Figure 4: Sampling of different calibration factors for the different manufacturers of ionization chambers.

4.1.1. Analysis of factors calibrations $N_{D,w}$

The results show the energy dependence (range; maximum and minimum) and the average value of calibration factors, and yet the uncertainties for each model of clinic dosimeter system tested. The clinic dosimeter system that shows the lowest variation between the maximum and minimum value of $N_{D,w}$ was the model PTW TN30013, otherwise the model that shows the highest variation was the Exradin A12 Ns.: Only Number; both systems were calibrated and their responses (maximum and minimum) for that models are very. A great number of equipments model PTW TN30013 were tested, but their response showed the lowest variation in calibration factor if compared with the others models tested. The knowledge of the behavior of the systems can help the worker in their control quality routines, and yet to prevent some failure, trouble in the systems and to obtained very high accuracy in the measurements with that system.

With the values of average $N_{D,w}$ and its uncertainty of different models of ionization chambers has been implemented in the laboratory calibration of dosimeters clinical radiotherapy a parameter initial comparison to these models.

This study of calibration factors, $N_{D,w}$, de different clinical models of sets was sent and accepted for publication in the conference International Conference on Medical Physics (ICPM-2011), in Porto Alegre – RS, Brasil, in Pontifícia Universidade Católica of Rio Grande do Sul PUC-RS.

4.2. Study the sensitivity of clinical dosimeters

We analyzed the equipment showed no calibration conditions. We used the leakage current test for determining the defect. In the eight-month period examined different equipments belonging to institutes, clinics and hospitals have sent their dosimeters for clinical IPEN to calibrate. Thus, tests were conducted repeatability, leak test and test reproducibility in dosimetric systems. All ionization chambers were tested instruments that were already in use.

To determine the leakage current test was described in document leak IEC-60731 [8]. In Table 3 are presented with data on the equipment nonconformity analyzed.

Table 3 - Data on the relative amount of equipment analyzed for quantity of defective equipment (%)for each type of ionization chamber analyzed.

Clinical Group			
Ionization Chamber	**Number of Equipment**	**Number of Eq. with Defect**	**%**
NE 2571	10	3	30
Exradin A12	19	10	53
Wellhofer	6	0	0
PTW TN30013	20	1	5
SNC 10-730	1	1	100
SNN 100730	1	0	0
IBA FC65-G	4	0	0
INOVISION 580-006	1	0	0
Total:	**62**	**15**	**24**

Thus it can be seen in Table 3 the ionization chamber Exradin A12 has the largest percentage of defective equipment in relation to the number of devices that were calibrated. In Table 4, presents the defects specific to each clinical dosimeter.

Table 4: Defects corresponding to each set clinical

Clinical Group who presented Defect			
Nº.	**Ionization Chamber**	**electrometer**	**defect**
1	Exradin A12	Standard Imaging CDX 2000B	Leakage current
2	NE 2505/3B	NE 2502/3	broke
3	SNC 10-730	SUN 1010	broke polarization
4	Exradin A12	Standard Imaging CDX 2000A	Leakage current
5	NE 2581	NE 2571/1B	broke
6	Exradin A12	Standard Imaging MAX 4001	Leakage current
7	Exradin A12	SUN Nuclear 1010	Leakage current
8	Exradin A12	Standard Imaging MAX 4001	Leakage current
9	Exradin A12	Standard Imaging CDX 2000A	Leakage current
10	Exradin A12	Standard Imaging CDX 2000A	Leakage current
11	PTW N300	CNMC 11	broke battery
12	Exradin A12	Standard MAX 4000	Leakage current
13	NE 2571	NE 2502/3	broke
14	Exradin A12	Standard Imaging CDX 2000A	Leakage current
15	Exradin A12	Standard Imaging CDX 2000B	Leakage current

In Table 3 and 4, it is found that there is a defect in the incidence of clinical assembly comprising an ionization chamber Exradin A12 e electrometer Standard Imaging more (53%) for equipment with defects.

By studying the possible defect that occurs in these sets comes to the conclusion that this defect is the leakage current in the ionization chamber.

The ionization chamber model Exradin A12 is waterproof and does not require *holder* to be positioned in *phantom*. Knowing that the ionization chambers are very sensitive to relative humidity, these should be accomodated humidities between 45 a 60 %. In this project, experiments were performed to test leakage current [8] in ionization chambers Exradin A12 showed that defective. In Fig. 5 presents the results of a test conducted in leakage current ionization chamber Exradin A12 and testing performed in standard clinical dosimeter used at IPEN in the same period (days) that conducted the ionization chamber A12 Exradin.

So with the data presented in the current leakage test, the percentage rate of change of escape proved far above the acceptable (± 0.58%) according to IEC-60731[8]. Possibly there was a leakage current per occurrence of water infiltration (if specific camera operation Exradin A12) or the influence of relative humidity higher at this point in contact with the water in the ionization chamber during testing.

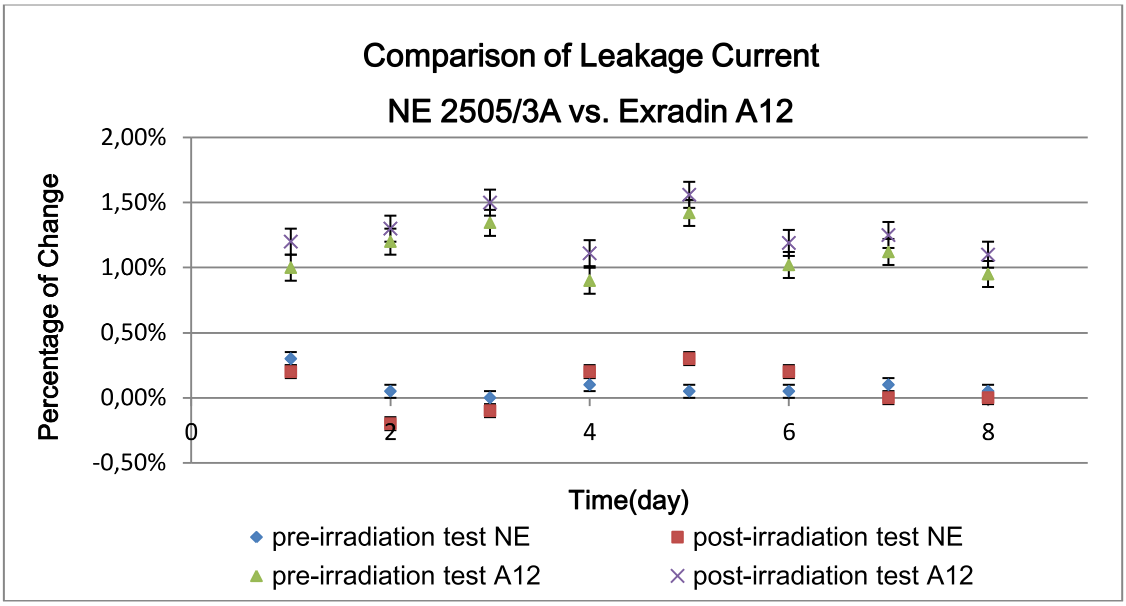

Figure 5: Comparison test leak ionization chamber Exradin A12 and NE 2505/3A.

4.2.1. Analysis of the sensitivity of clinical dosimeters

Not all ionization chambers Exradin A12 that present this kind of behavior, but in relation to the percentage of the context of calibration of equipment problems, the Exradin was the most frequently presented defect. This had the same problem in all cases. Thus the operator of this equipment must take care bent, as always keep it stored in a greenhouse, using it to see if was well fenced, and testing often, so he could have a control chamber. However, this type of camera care must be taken with all clinical dosimeter and every model / type of joint clinical, as well as reliability in relation to their dosimeter will be much larger and will be prevented leakage problems and possible logo unnecessary mistakes. For a simple careful with the stability of temperature and humidity of the environment can be avoided to a variation in the reading system and error in patient treatment and radiotherapy will make your equipment is reliable readings response.

4.3 Study of the reproducibility of clinical dosimeters

Further tests were performed repeatability and reproducibility of the set standard clinical LCI during the period May 2009 to June 2010, but the test repeatability is already done for the determination of the calibration factor for clinical dosimeters to be calibrated. Thus it was possible to analyze data from June 2003, when it started the calibration of dosimeters with this clinical reference equipment until June 2010. The repeatability test was performed periodically, where you can see this test in Fig. 6, approximately six times per month. This stability was evaluated analyzing the behavior of equipment decay of radiation source ^{60}Co, Fig. 7 and 8.

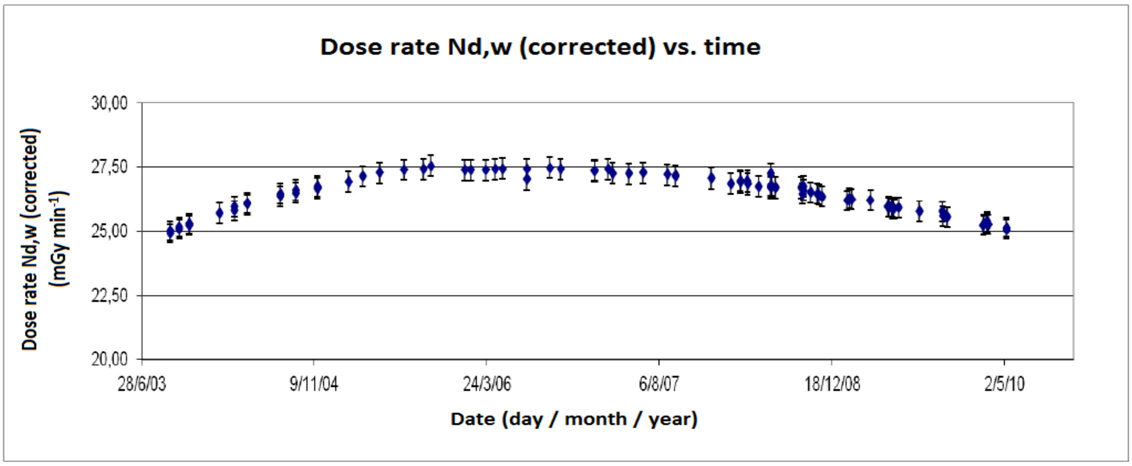

Figure 6: Graph dose rate by time. Shows the clinical behavior of the dosimeter with respect to time.

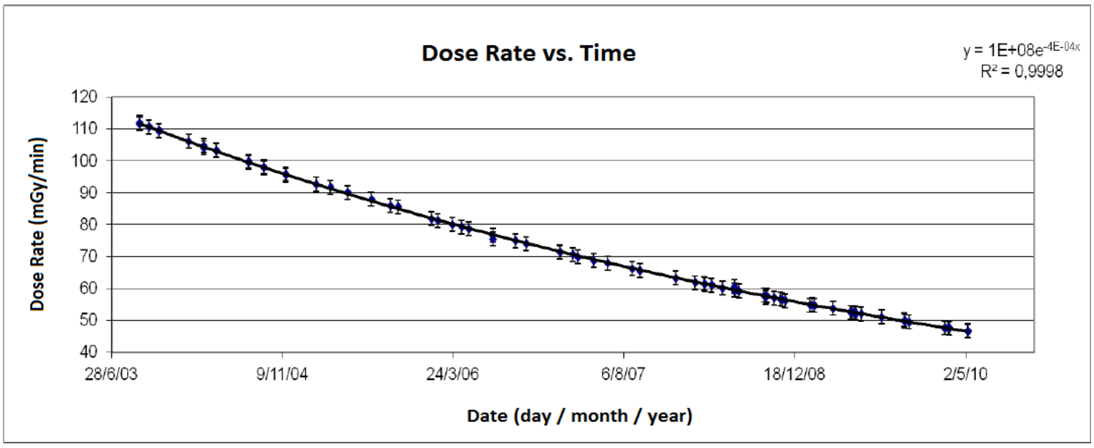

Figure 7: Graph of dose rate by time. (Demonstrates the behavior of the radioactive source irradiator LCI (disintegration characteristic of radioactive element ^{60}Co)).

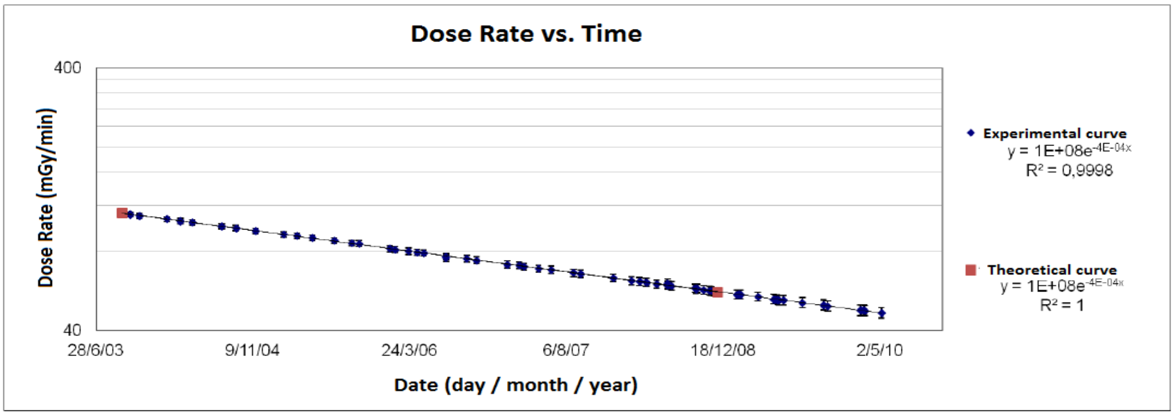

Figure 8: Graph of dose rate (monolog) at time. (Demonstrates the behavior of the radioactive source from the irradiator of LCI (to determine the rate of disintegration ^{60}Co)).

In the Fig. 8 can see the experimental and theoretical curves of the dose rate by time (rate of decay of the radioactive element ^{60}Co), where the theoretical curve was performed by two-point coordinate ([mGy/min]$_{stars}$, 9/18/2003) and (([mGy/min]$_{starts}$ /2), (9/18/2003 + 5,27 years)). Therefore it is possible to determine the values of λ, $T_{1/2}$ and τ theoretical and experimental graphically.

The following calculations were performed with the following equations to determine the values λ, $T_{1/2}$ e τ theoretical and experimental:

$$\lambda = \frac{\ln\left([\mathrm{mGy/min}]\mathrm{starts}\right) - \ln([\mathrm{mGy/min}]\mathrm{starts}/2)}{\mathrm{t}_1 - \mathrm{t}_2} \tag{1}$$

$$T_{\frac{1}{2}} = \frac{\ln(2)}{\lambda} \tag{2}$$

$$\tau = \frac{1}{\lambda} \tag{3}$$

Experimental:

$$\lambda = \frac{\ln(111{,}94) - \ln(49{,}52)}{18/11/2009 - 18/09/2003} = \frac{4{,}718 - 3{,}902}{6{,}17} = 0.132\ years^{-1}$$

$$T_{\frac{1}{2}} = \frac{\ln(2)}{\lambda} = \frac{0{,}693}{0{,}132} = 5.25\ years$$

$$\tau = \frac{1}{\lambda} = \frac{1}{0{,}132} = 7.58\ years$$

Theoretical:

$$\lambda = \frac{\ln(111{,}94) - \ln(55{,}97)}{5{,}27} = \frac{4{,}718 - 4{,}025}{5{,}27} = 0.131\ years^{-1}$$

$$T_{\frac{1}{2}} = \frac{\ln(2)}{\lambda} = \frac{0{,}693}{0{,}131} = 5.27\ years$$

$$\tau = \frac{1}{\lambda} = \frac{1}{0{,}131} = 7.63\ years$$

So the percentage difference for the experimental value is given to theoretical:

$$e\% = \frac{(\text{Theoretical} - Experimental)}{\text{Theoretical}}.100 \quad (4)$$

Values being:

- λ: $e\% = 0.76$
- $T_{1/2}$: $e\% = 0.34$
- τ: $e\% = 0.66$

4.3.1 Analysis of the reproducibility study of clinical dosimeters

Data provided by Fig. 6 show the percentage change in the value of the dose rate measured with the dosimeter clinical standard LCI the irradiator Teletherapy Siemens - model Gamatron - ^{60}Co. Thus we note the statistical fluctuation of the values of dose rate measured by this equipment (reproducibility over time). Factor was used in the decay rates of doses provided to correct the source activity and therefore the dose rate. We can observe a fluctuation of dose measurements with the set of standard clinical LCI, and this variation shows the characteristic behavior of a dosimeter clinical, noting that the maximum rate allowed by is ±1% [2]. The average dose rate obtained was 26.4 ± 0.3 (mGy min^{-1}), for a range of 26.1 a 26.7 (mGy min^{-1}) variation in two years that did not exceed the limit ±1%. Was also observed in Fig. 6 a level of operation of the clinical reference dosimeter (from 2005 to 2008) and therefore with the decrease in value of dose rate (lower detection efficiency with the passage of time) was expected that this device would lose its use for damage (behavior presented showed the existence of future problems in the ionization chamber). So in mid-2010 ionization chamber standard LCI no longer had conditions of use. Therefore analyzing the behavior of the reproducibility of the set as a whole is clinician can observe the radiation detection efficiency of the detector over time.

In Figure 7 shows the variation of the dose rate by time. It is possible to observe an exponential curve because of the radioactive decay of the element (^{60}Co). As the element has a half life of approximately 5.27 years was possible, his period of data analysis, observe more than two half-lives, and determine the values of rate of disintegration, physical half-life and average life ^{60}Co.

In Figure 8 shows the experimental and theoretical curves. Therefore it was possible to determine the values of λ, $T_{1/2}$ e τ theoretical and experimental plot. And their values of percentage errors of the theoretical value with the experimental value were to λ: $e\% = 0.76$, to $T_{1/2}$: $e\% = 0.34$, to τ: $e\% = 0.66$ Soon the values obtained were very close to the theoretical, demonstrating the efficiency dosimetric system composed of radiating ^{60}Co dosimeter and clinical reference LCI.

From Fig. 6-8 presented can be seen that if carried out thorough monitoring of all clinical data can be obtained for the analysis of the behavior of equipment and emitting radiation.

5. CONCLUSIONS

The criterion that the laboratory calibration of dosimeters clinical radiotherapy LCI was used to analyze the reproducibility of the new value of the acquired calibration factor by factor of previous calibration of this equipment. The maximum allowable percentage change was of ±1%, therefore if the product does not present a variation less than ±1% the equipment was studied as a whole in order to eliminate this defect that caused this variation. However, the time length the equipment stayed in the lab to solve the problem or provide the report not conforminade was too long, delaying other calibrations and leaving the user without his equipment for a long time.

As the lab improvements took place, new tests and different criteria were created to speed up the process of calibration or issuance of reports of non-compliance. By doing so, the time of calibration and the trustability in the factor of calibration sent to the users increased significantly, making it noticible in the lab routine. Therefore, updating constanly the system is paramount to decrease errors and time wasted during the calibration routine.

This study has added three new criteria to the calibration lab routine, increasing the system of quality laboratory at the calibration lab of clinic dosimeters owned by the LCI.

From the results presented it is concluded that the periodic calibration of a clinical dosimeter is essential for achieving the necessary levels of reliability and quality in radiotherapy treatment because this test certifies that the operator is taking due care with clinical and dosimeter by following ensures quality control of radiotherapy treatment. Soon demonstrating the importance of the dosimeter clinical treatment following radiotherapy and the importance of not only carrying out the calibration only this, but also the completion of a thorough monitoring of all clinical, the ionization chamber, cables, electrometer, connection of the connectors on the set and the electrometer throughout his life.

Therefore, the pre-calibration procedure the dosimeters described by clinicians IEC-60731 can be used by operators of the equipment in hospitals, clinics, research institutes, self to the quality of your measuring instrument, and soon will have your measurements reliability However the importance of carrying out the calibration is essential for the optimization of errors in radiotherapy treatment, making the testing routine Additional equipment is very important for an addition to periodic calibration. So bringing reliability to clinical dosimetry and packaging of radiators, since the instrument that certifies the quality and results of functions, is in perfect condition and immediately use its measures have reliability and quality measurement.

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