Calibration of a Dosimetric System in Hp (3) using a cylindrical phantom

Andrea Castillo (acastillos@unan.edu.ni); Josselyn Mendoza; Norma Roas; Freddy Somarriba

Laboratorio de Física de Radiaciones y Metrología LAF-RAM, Universidad Nacional Autónoma de Nicaragua, Managua Rotonda Universitaria Rigoberto López Pérez 150 metros al este, Código postal: 663 Managua, Nicaragua

Abstract- In Nicaragua the Laboratory of Radiation Physics and Metrology (LAF-RAM) has currently the only external dosimetry service provider at national level. During the last meeting between LAF-RAM and stakeholders it was agreed to provide monitoring of dose in the lens of the eye in Hp(3) which is in accordance to the recommendations of ICRP 118. This paper highlights the process and results of the LAF-RAM to achieved the characterization of the dosimetry system in this quantity.

Some measurements and comparisons where performed between the type of thermoluminescent materials, conversion coefficients and standards and type of phantom. The first approach was using MCP-N detectors using a conversion coefficient for Hp (3) of 1,226 Sv/Gy described in ISO 12794 for ^{137}Cs and slab phantom for irradiations. The second approach was using the same conditions for calibration as the first one except that TLD-100 material was used.

For the last characterization MCP-N and cylindrical phantom locally manufactured with the technical specifications proposed in ISO 4037-3: 2019 was used and the conversion coefficient of 1,18 Sv/Gy for ^{137}Cs. During the calibration of the dosimetry system comparison of the doses of Hp(3) was carried out with dosimeters irradiated with the slab phantom and with the cylindrical phantom, finding a relative percent error of 6,1 % and 3,6 % respectively with respect to the reference value.

Keywords; Calibration; Conversion coefficient; Cylindrical phantom

1.INTRODUCTION

The International Commission on Radiological Protection (ICRP) in 2007 maintained in its recommendations an occupational dose limit of 150 mSv per year [1]. However, due to the evidence of higher incidence of damage such as cataracts at low doses and with the aim of contributing to the revision of work procedures to reduce the risk, the ICRP in 2012 in its publication 118 recommends an absorbed dose threshold in the lens of the eye of 0,5 Gy and also reduces the occupational dose limit to 20 mSv as a 5-year average and not to exceed 50 mSv in a single year [2].

In Nicaragua, personal dosimetry of occupationally exposed workers is performed by the External Dosimetry Laboratory (LDE) which is part of the Radiation Physics and Metrology Laboratory (LAF-RAM) of the National Autonomous University of Nicaragua, Managua.

LAF-RAM has implemented a Quality Management System based on ISO 17025 since 2018 and currently follows the 2017 version. This has allowed a greater rapprochement and openness between LAF-RAM with the different figures or stakeholders, therefore, in 2018 a meeting was held with representatives of the medical area such as public and private hospitals, industry area and with the regulatory authority. The requests and commitments produced in this meeting were the opening of the eye lens dosimetry service in Hp (3) and following the recommendations of ICRP 118.

Previously, LAF-RAM had already carried out the first investigations to provide dosimetry in Hp(3) by first performing the calibrations of the dosimetry system following different international protocols with the available equipment.

The first effort for dosimetry in Hp(3) quantity was carried out in 2014. On this occasion the scope was only the calibration of the dosimetry system through the characterization of thermoluminescent dosimeters (TL), material type MCP-N (LiF:Mg,Cu,P). These detectors present greater sensitivity and adaptation to measure the dose of incident radiation in the eye lens, using dosimeter holders with filters that simulate a depth of 3mm. Nevertheless, the availability of this type of detectors to provide the service was of only 80 dosimeters. On the other hand, the calibration was performed following the irradiation conditions of ISO 12794:2000 which indicates the use of the slab phantom as appropriate for irradiations in Hp (3); besides it was the only phantom available in the laboratory.

A subsequent study conducted in 2017, had a larger scope with respect to eye lens dosimetry as measurements were performed in two private hospitals over a six-month period on 25 occupationally exposed workers in the interventional procedure area. In this research, however, it was used a different thermoluminescent material (TLD-100) since there were a greater number of detectors available. This work included again the calibration of the dosimetry system, type tests under IEC:1066:1991 and additionally Hp(3) lens of the eye measurements using the same type of dosimeter holder. Calibration was also performed according to the irradiation recommendations of ISO 12794.

A third approach for dosimetry in Hp (3) was performed in 2020 considering the current standards for dosimetry and calibration which include lens of the eyes dosimetry using the cylindrical phantom configuration. The phantom was manufactured locally following the specifications of its dimensions described in 4037-3:2019. Therefore, the calibration of the system was again developed using MCP-N thermoluminescent dosimeters; moreover, type tests were performed following the requirements proposed in 62387:2012.

2.MATERIALS AND METHODS

To start the calibrations, the dosimeters must be characterized, in this sense, the laboratory procedure has been to use dosimeters with individual factors of individual zero dose and sensitivity. With these first factors, the reader's sensitivity is determined, which is specific for each magnitude and type of material. Subsequently, the dosimetry system is calibrated by determining the value of the factor, which relates the known dose from a standard reference source to a local verification source.

The LAF-RAM uses as local source a table irradiator with a $^{90}Sr/^{90}Y$ source of the Radpro company which in the exposure mode rotates at a certain pre-set number of turns, irradiating the thermoluminescent crystals (see figure 1a). Therefore, the calibration factor of the system is a function of the Equivalent dose per number of turns (μSv/turn). The Rados RE 2000 reader system is shown in Figure 1b.

Figure 1a. IR-200 irradiator, the TLD crystals are placed on a disk that rotates when in exposure mode. Figure 1b Thermoluminescent dosimeter reader, uses a coded card system where the crystals are placed.

Moreover, the LAF-RAM has a Dosimetry Calibration Laboratory (LCD) equipped with a calibration bench, a 22 Ci reference source of ^{137}Cs as of July 1, 2013 and 1 liter and 10 liter standard chambers, where the irradiations of the dosimeters were performed with the different methodologies and specifications available.

First calibration in Hp (3)

A batch of 40 dosimeters was used for the study, 16 of which were selected because they had a variation coefficient of less than 5%; the dosimeters were separated into two batches to calibrate the dosimetry system. Dosimeters TL MCP-N distributed by RadPro International GbmH were used, arranged in EYE-D type dosimeter holders developed by the Optimization of RAdiation protection for MEDical staff (ORAMED) project, as shown in Figure 2.

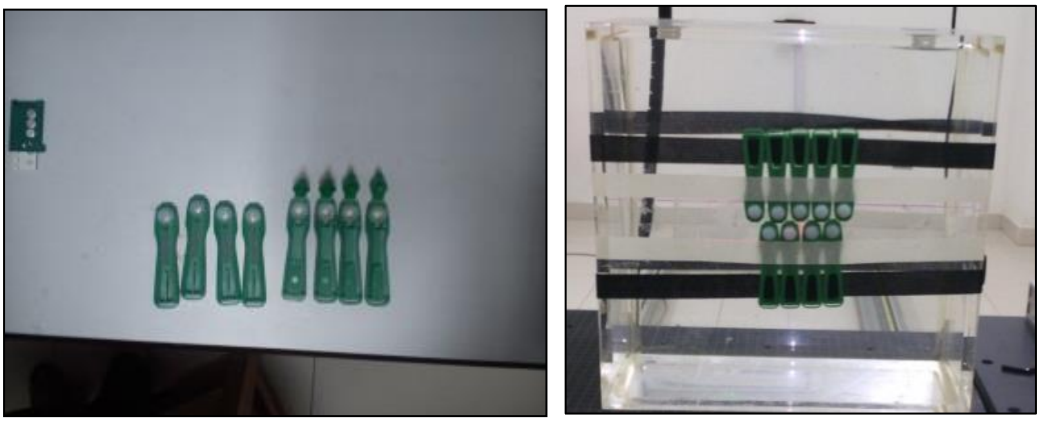

Figure 2. Type of dosimeter holder used for Hp (3) dosimetry. The detectors are then assembled on the pellet carrier cards for readings in the equipment.

As shown in Figure 3 the first group of dosimeters were irradiated at 1 mSv on the LCD at 1 m distance on the slab phantom, the conversion coefficient 1,226 of ISO 12794 was used for energy quality of ^{137}Cs for calibration in personal dose equivalent Hp(3) with an incidence angle of zero degrees, no build up layer was used [3].

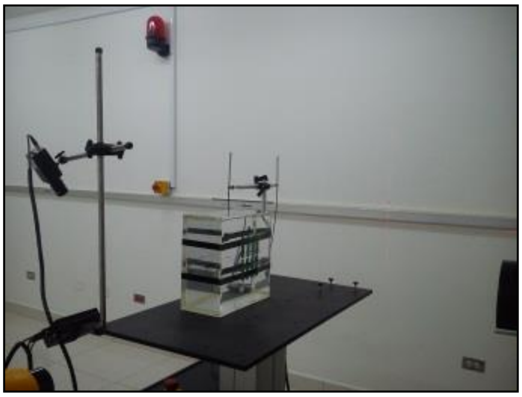

Figura 3. Posicionamiento de los dosímetros en el slab phantom para irradiaciones.

The other group of dosimeters were exposed to 10 turns in the local irradiator mentioned above (IR-200), this in order to determine the calibration factor of the local irradiator as a function of μSv/turn.

Both groups of dosimeters were read 24 hours post-irradiation using a temperature of 250°C, Pre heat time of 3 seconds, readout time 22 seconds and Post heat time 5 seconds. The μSv/turn factor was obtained from the ratio of the reference dose of 1 mSv to the dose obtained by the respective readings as described in equation 1.

$$f = \frac{1mSv}{Hp(3)[mSv]estimated} \qquad \text{Eq. 1}$$

The product of this factor with the dose of the dosimeters irradiated in the IR-200 and the quotient with respect to the number of turns gave as a result the final calibration factor of 417 μSv/turn.

Second calibration in Hp (3)

Harshaw TLD-100 dosimeters were used for this study (see Figure 4). It was decided to use this material even though its configuration differs from those used by the current reader system, since there were more pellets available for monitoring the occupational workers.

Figure 4. Example of the shape of the TLD-100 dosimeter, also showing the position inside the coded card.

The calibration procedure was the same as described above, where a calibration factor of 292,9 μSv/turn was obtained [4]. With the system calibrated in Hp(3), a batch of 140 dosimeters was characterized to perform the type tests and the monitoring of workers in the interventional procedure area. The type tests were performed following the IEC 1066:1991 methodology. Irradiations for verification of test requirements were performed both on the LCD using the slab phantom and irradiations with the IR-200.

The results of the type tests such as: linearity of the dosimeter response to radiation, homogeneity of the batch, minimum detectable, fading or loss of information, coefficient of variation and angular dependence obtained positive results in compliance with the requirements of the standard [4].

The Hp(3) dose monitoring of 20 users was performed in one of the largest hospitals in the capital of the country and the monitoring of 5 users in a hospital in another province. The monitoring periods were different between the two hospitals since the dosimeter change periods were two months and one month for the hospital in the capital and the hospital in the province, respectively.

The results for eye lens equivalent dose in Hp (3) did not exceed the ICRP 118 recommendations of 20 mSv per year; however, in some cases doses higher than 1 mSv were observed [4].

A critical point at the time of this research was the interruption of the service again due to the availability of a limited batch of dosimeters and holders.

Third calibration in Hp (3)

Due to the implementation of the quality management system at LAF-RAM, the dosimetry service in Hp (3) had to be formally opened; for this it was necessary to perform the calibration process again.

With the new version of ISO 4037-3:2019, which specifies the irradiation conditions of personal and area dosimeters, incorporating a new head phantom simulator for dosimeter irradiations in Hp (3) operational quantity.

The LAF-RAM did not have a cylindrical phantom to meet the irradiation conditions of ISO 4037-3:2019, therefore, to acquire it, it was necessary to have it manufactured locally. The phantom complies with the technical specifications since it is a hollow cylinder with PMMA walls with an outer diameter of 200 mm, length of 200 mm, thickness of 5 mm [5], as shown in Figure 5.

Figure 5. Locally manufactured cylindrical phantom. The cylinder is filled with water for irradiations

The irradiation conditions according to ISO 4037:2019 were: conversion coefficient of 1,18 Sv/Gy (at 0°) for the reference source type used which is ^{137}Cs, 3 mm of PMMA as build up layer and a source distance of 2,5 m [5].

In this last attempt to calibrate the system, MCP-N type TLD material was used and the calibration protocol described in the External Dosimetry Laboratory procedure was followed based on the reader manual. Two groups of 10 dosimeters each were divided, one group was irradiated at a dose of 3 mSv on the LCD. Figure 6 shows the setup performed by the LCD team to carry out the irradiation. Another group of dosimeters was left unirradiated and used for background. After 12 to 24 hours, the dosimeters were read out, annealled and irradiated at 5 turns at the local IR-200 source [6]. According to the procedures, the readings of each batch were assigned in the reader software to three different configurations and commands: standard dose system calibration, background or transport calibrations and local dose system calibration. The software then runs a calculation algorithm with these readings to generate the value of the system calibration factor.

Figure 6. Dosimeter irradiation setup with the 137Cs reference source on the LAF-RAM LCD.

Following the procedures of the management system it was necessary to verify the performance characteristics of such dosimeters. Therefore IEC 62387:2012 was followed, where the methodology and tests to be developed according to the acceptance criteria are established; since in this version the technical requirements for dosimeters used to measure the personal equivalent dose Hp (3) are added. On the other hand, the value of the calibration factor was also verified by performing the dose linearity test as a function of the number of turns, in this sense a batch of dosimeters was irradiated at 1,3, 5, 7, 10 turns.

Comparison of irradiated eye lens dosimeters in slab phantom and cylindrical phantom

For all of the above, it was considered appropriate to know what is the deviation of the doses in Hp (3) in the case of not having a cylindrical phantom but using the irradiation conditions of ISO 4037-3:2019 in terms of conversion factor, distance and buildup layer. Therefore, to perform this comparison, a batch of 20 dosimeters was used which were divided into two groups consisting of 10 dosimeters, one group was irradiated on the slab phantom and the other group on the cylindrical one, the two groups were irradiated at 1mSv on the LCD [6].

3.RESULTS AND DISCUSSION

First and second calibration in Hp (3)

The calibrations performed in both studies are not comparable since they were performed with thermoluminescent dosimeters of different materials, both investigations had equipment limitations and therefore no continuity was given, however, the specific objectives of each study were met.

Third calibration in Hp (3)

Following the calibration procedures and irradiation protocols based on current standards, a calibration factor value of 350,14 µSv/turn was obtained in the dosimetry reading system with RADOS-2000 equipment of the LAF-RAM. With the system calibrated, we proceeded to characterize the rest of the dosimeters available for monitoring in Hp (3) and a total of 357 field dosimeters were characterized.

Figure 7 shows the results of linearity of the evaluated dose with respect to the number of turns, with a regression coefficient R^2 value of 0,9987, indicating that the value of the calibration factor is acceptable.

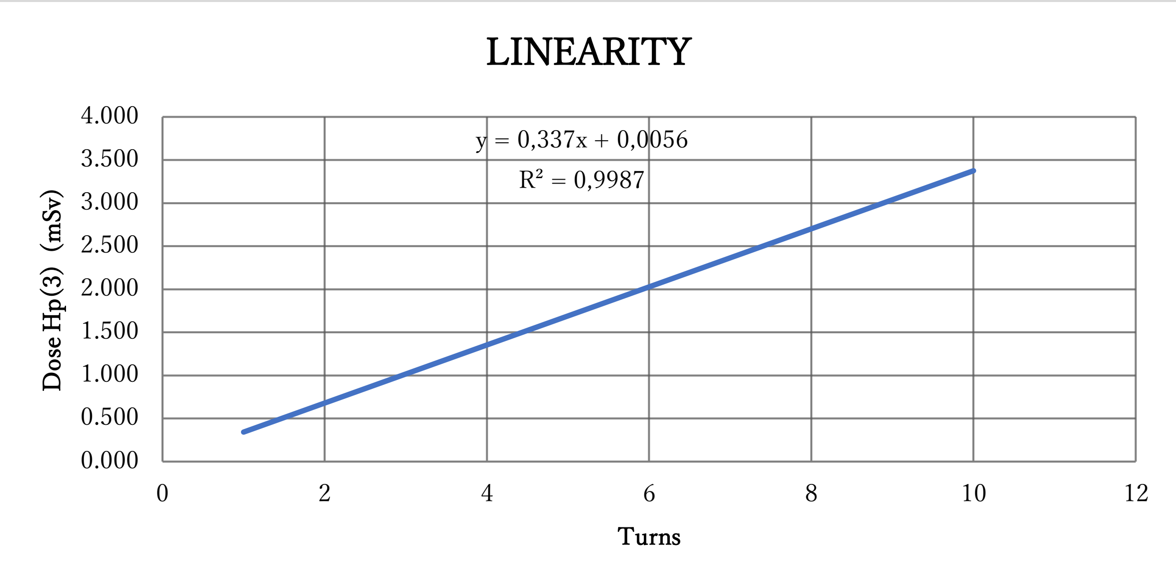

Figure 7. Linear trend of the dose as a function of the number of turns selected in the IR-200. The equation of the line with acceptable regression coefficient is also shown.

In the case of the type testing, the tests developed are coefficient of variation, non-linearity of response, light exposure, dosimeter drop, over response to radiation incidence, dosimeters at 180° and dose build-up, fading, self-irradiation, and response to natural radiation (dosemeter). The requirements are in generally satisfactory, except for some of the temporary conditions in the test of Dose build-up fading.

Regarding the comparison of the doses between the type of phantom used, a relative percentage error with respect to the reference value of 6.1% and 3.6 % was found for the doses evaluated with the slab phantom and cylindrical one, respectively.

The average dose values obtained are shown in Table 1, where the dosimeter codes for each group are also presented, the typical uncertainty u is also reported. In the case of the group of dosimeters irradiated with the cylindrical phantom, a pellet was damaged during the mounting of the dosimeter holder to the reading card.

Table 1: Comparison of evaluated doses of dosimeters irradiated at 1 mSv in using both type of phantoms

Group of irradiated dosimeters on cylindrical phantom		**Group of irradiated dosimeters on slab phantom**	
Code	**Equivalent Dose Hp (3) [mSv]**	**Code**	**Equivalent Dose Hp (3) [mSv]**
17079	0,946	17129	1,043
17078	0,922	17128	1,076
17077	0,949	17126	1,026
17076	1,004	17127	1,062
17074	0,952	17125	1,038
17073	0,976	17124	1,075
17072	0,957	17165	1,087
17071	1,015	17166	1,065
17080	0,958	17167	1,057
		17164	1,084
Average	**0,964**	**Average**	**1,061**
u [mSv]	**1x 10^{-2}**	**u [mSv]**	**6 x10^{-3}**

4.CONCLUSION

First and second calibration in Hp (3)

Both studies were the basis for the beginning of monitoring in the country at the Hp (3) quantity, although with different scopes and not so visible results, such as: training and familiarization of LAF-RAM personnel of both LDE and LCD; dissemination among interested parties of the opportunity of lens monitoring.

Third calibration in Hp (3)

All the MCP-N dosimeters used in this study were successfully characterized, having been assigned the sensitivities of zero dose and individual crystal sensitivity with acceptable values as established in the LAF-RAM procedures.

The calibration of the dosimetry system is considered satisfactory since the value of the calibration factor 350,14 μSv/turn was verified as a result of the correspondence of the linearity of the dose as a function of the number of turns.

The comparison tests between the type of phantom indicate that with the use of the cylindrical one, a smaller percentual relative error of 3,6% is observed when comparing the measurements obtained with the reference value, with respect to the slab, where a greater value of 6,1% is obtained. In general, although the origin of the cylindrical phantom is not commercial, its manufacture is considered adequate and was successful since it has allowed the homogenization of the LCD in terms of irradiation protocols with the rest of the countries in the region, including the participation in inter-comparison exercises.

Although the number of dosimeters available for this quantity is limited, LAF-RAM can comply with the commitment acquired with the users and begin to meet the existing demand for lens dosimetry based on the personal dose equivalent Hp (3), thus complying with national regulations as a service provider, even considering international recommendations.

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