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First Latin American and Caribbean interlaboratory comparison exercise for SSDLs on reference irradiation capabilities in personal dose equivalent

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Abstract

A comparison exercise of Latin American and Caribbean Secondary Standards Dosimetry Laboratories (SSDLs) was jointly organized by the International Atomic Energy Agency (IAEA) and the Ionizing Radiation Metrology Laboratory at the Federal University of Pernambuco (LMRI-DEN/UFPE). This exercise was organized during an IAEA regional meeting on the review and update of calibration capabilities in Latin America, held in Recife, during the period from 23 to 27 April 2018 under the technical cooperation project ME-RLA 9085-170572. Fifteen participating SSDLs were required to irradiate optically stimulated personal dosimeters in terms of the personal dose equivalent Hp(10) in ^{137}Cs radiation quality. In addition, the IAEA Dosimetry Laboratory in Seibersdorf, Austria, and the National Physical Laboratory in Teddington, Middlesex, UK participated in this exercise as reference institutes. Each participant received 10 dosimeters that were hand-carried directly to the SSDL. Two nominal dose values of 2 mSv and 4 mSv were selected for this exercise. The participants irradiated the dosimeters using the setup and the procedures which are normally used in their standard laboratory for Hp(10) dosimeter irradiations. The dosimeters were evaluated as they were received by the coordinating laboratory, using a single BeOSL Reader. The results show that, except for one laboratory, the differences between the dosimeter reading and the assigned values were within 10%; this is consistent with the expanded uncertainty. The results indicate that most of the participant laboratories have a good capability to irradiate personal dosimeters in the quantity Hp(10).

Keywords: personal dosimeter irradiation, comparison exercise, personal dose equivalent Hp(10)

(Some figures may appear in colour only in the online journal)

1. Introduction

Nuclear techniques are widely used in medical, industrial, agriculture, energy, environmental and research applications. Despite its benefits, ionizing radiation represents a risk for both users and members of the public. For this reason, it is necessary to limit radiation doses received by workers, patients, and the population in general following international requirements such as the International Basic Safety Standards [1]. The Safety Standards Series N. GSG-7: Occupational Radiation Protection [2] provides general guidance on the exposure conditions for which radiation protection programs are required to be established. Individual monitoring and personal dosimetry form the basis for assessment of the risk from ionizing radiation. A proper calibration of the dosimetry system is important to achieve consistent and accurate measurement results.

Personal dosimetry services maintain their traceability to the international measurement system through reference irradiation of their dosimeters by Secondary Standards Dosimetry Laboratories (SSDLs). The SSDLs irradiate the dosimeters on a slab phantom and determine the reference Hp(10) value based on measurements with their reference standard, which is traceable to a primary standard. Typically, the Hp(10) value is calculated as a product of the measured air kerma and conversion factor obtained from ISO 4037.

The International Atomic Energy Agency (IAEA), together with the World Health Organization, coordinates the IAEA/WHO SSDL Network [3], which is an association of national SSDLs that have agreed to cooperate in promoting the objectives of that network under international auspices. Their objectives are: (a) to provide dosimetry services and create and disseminate knowledge in radiation dosimetry in order to improve the accuracy levels of dose measurements; (b) to establish traceability between end users of dosimeters, the SSDL members and the SI (International System of Units) system for radiation measurements; (c) to promote international recommendations on methods applied for calibration and performance of dosimetry in order to achieve consistency of measurements in all countries; and (d) to promote further the exchange of experience between the members and the metrology community, and to provide support to each other where necessary [3].

The IAEA TECDOC 1763 [4] highlights the need for further development and strengthening of individual monitoring of occupationally exposed workers, radiation protection of patients and of dosimetry calibration services in Latin America and the Caribbean. As part of the regional technical cooperation project ME-RLA 9085-170572, the IAEA organized a regional meeting on the review and update of calibration capabilities in the region. The aim was to define the need for establishing new or upgrading the scope of existing SSDLs in the region. The meeting was held in Recife, Brazil, during the period from 23 to 27 April 2018. A total of 36 participants from 19 countries attended the meeting and were supported by one expert from the Radiation Protection Center, Cuba, and two experts from the National Physical Laboratory

(NPL), United Kingdom, as well as two IAEA staff. The status of the calibration capabilities in the region was reviewed and discussed. Important aspects such as training, quality management systems and technical protocols and procedures were discussed and opportunities for improvement were identified. It was also observed that the implementation of Quality Management Systems according to International organization for standardization and International electrotechnical commission (ISO/IEC) 17025:2017 on each SSDL in the region is at a different stage [5] and there is a need for capacity building on this topic.

Since most of the operational SSDLs have established calibration services for radiation protection equipment using ^{137}Cs sources, it was decided to use this reference quality for the first interlaboratory comparison of dosimeter irradiation capabilities. The IAEA provides comparison services for Member States in terms of air kerma by using a transfer ionization chamber [3], but for this exercise it was decided to use a good quality passive personal dosimeter, small in size and easy to ship when compared to more fragile ion chambers.

The protocol for the interlaboratory comparison exercise was discussed and implemented as a result of the regional meeting. With the support of the Ionizing Radiation Metrology Laboratory of the Federal University of Pernambuco (LMRI-DEN/UFPE), participants who agreed to join the exercise received a set of dosimeters to be irradiated in their laboratories. This is the first step of a set of comparison activities proposed during the meeting and aims to verify the performance of the participating SSDLs to irradiate personal dosimeters in terms of the personal dose equivalent Hp(10) in ^{137}Cs radiation beam and improve the calibration technique for personal dosimeters in the region.

2. Material and methods

Altogether, 15 laboratories from the following 13 countries of Latin America and the Caribbean region participated in the comparison exercise: Argentina, Bolivia, Brazil, Cuba, Chile, Colombia, El Salvador, Nicaragua, Guatemala, Mexico, Nicaragua, Uruguay, and Venezuela. Each country participated with one SSDL, except for Brazil where four laboratories participated. In addition, the IAEA Dosimetry Laboratory in Seibersdorf, Austria, and the NPL, in the United Kingdom, were included as key participants in this exercise. NPL has a primary air kerma standard for ^{137}Cs radiation and ensures the traceability of the reference Hp(10). The coordinating institution was the Metrology of Ionizing Radiation Laboratory of the Federal University of Pernambuco (LMRI-DEN/UFPE), Brazil, which did not participate in the exercise.

The transfer instrument for the Hp(10) determination was a personal Optically Stimulated Dosimeter, manufactured by Dosimetrics GmbH, in plastic encapsulation, as worn by users. This dosimeter uses one beryllium oxide chip as the detector element for Hp(10) and one for Hp(0.07). The Hp(10) detector is covered with a filter made of Teflon and the Hp(0.07) detector is covered by a thin plastic layer. The filter of the Hp(10) element is made of Teflon with 2.4 mm thickness and the Hp(0.07) element is covered by 0.5 mm thick plastic window. This Optically stimulated luminescence (OSL) -System is accredited according to DIN IEC 62387 and obtained the corresponding type approval by the Physikalisch-Technische Bundesanstalt- Germany (PTB), the national metrology institute in Germany. We included this information in the text [6]. Each participant received during the meeting 10 dosimeters, which were hand-carried directly to the SSDL, together with detailed instructions explaining the protocol for irradiation. The following describes the technical irradiation protocol provided to participants.

3. Technical protocol for irradiation

Irradiations are restricted to the ^{137}Cs-photon radiation and will be carried out in the participating facility in terms of Hp(10) applying the following values:

(a) Three dosimeters with 2 mSv;
(b) Three dosimeters with 4 mSv.
(c) Angle of incidence: 0°.
(d) Irradiations should be performed on an International commission on radiation units & measurements (ICRU) slab water phantom.

The participant laboratory shall use the setup which is normally used for such irradiation in their standard laboratory procedure. Details of the procedure shall be given in the irradiation form. The reference point is the geometric center, corresponding to the position of the crystal.

The participants irradiated the dosimeters using a standard ^{137}Cs-source radiation beam (S-Cs-137) and under their individual procedures that were regularly used for Hp(10) irradiations. Participants were asked to irradiate three dosimeters with 2.0 mSv and another three with 4.0 mSv. They were also asked to fill out a formulary with the corrected dose which was delivered to the dosimeter. Four additional dosimeters were stored together with those irradiated to estimate the background radiation. The protocol established that dosimeter irradiations should be performed on the surface of the ICRU slab phantom with an angle of incidence of 0°, in accordance with ISO 4037-3 [7]. After irradiation, the participants returned the dosimeters to the coordinating laboratory by international courier with the minimum possible delay. The participants were also asked to declare an uncertainty budget for the reference irradiations in Hp(10) according to the ISO/IEC Guide to the Expression of Uncertainty of Measurement [8].

The dosimeters were read as they were received by the coordinating laboratory, using the same BeOSL Reader, previously calibrated in the Laboratory of Radiation Protection of the Nuclear Energy Department of the the Federal University of Pernambuco. However, it is important to emphasize that, since the dosimeters irradiated at NPL were used as a reference for comparison, this calibration will not influence the comparison result. The average response of the four unirradiated dosimeters (BG) was subtracted from the response of the irradiated dosimeters to obtain the net value. The average of the three net values of irradiated dosimeters was then calculated.

To evaluate the laboratory performance, the declared irradiation value X, informed by the participant as the best estimate of the Hp(10) actually delivered to each dosimeter, was used to determine the value for the estimate of the laboratory bias D (see ISO 13528 [9]), in units of mSv, according to equation (1).

$$\mathrm{D} = \bar{x} - X. \tag{1}$$

Furthermore, the ratio (A) between the average of the result from each participant ($\bar{x}$) and the participant-declared value was calculated by equation (2), as well as its associated uncertainty given by equation (2).

$$\mathrm{A} = \frac{\bar{x}}{X}. \tag{2}$$

The combined standard uncertainty, u_A was calculated using equation (3):

$$u_\mathrm{A} = \sqrt{\left(\frac{1}{x} \cdot u_1\right)^2 + \left(\frac{\bar{x}}{x^2} \cdot u_2\right)^2} \tag{3}$$

Table 1. Information sent by the participant laboratories on the procedures and values used to irradiate the dosimeters.

Laboratory	Distance from the source to reference plane (cm)	Uses PMMA buildup plate	Thickness of the buildup plate (mm)	Declared value of Hp(10) irradiation (mSv) $\pm$ U_{95} (%)
A	150	No	—	2 $\pm$ 6 4 $\pm$ 6
B	50	Yes	3	2 $\pm$ 10 4 $\pm$ 10
C	150	Yes	2	2 $\pm$ 6.8 4 $\pm$ 6.8
D	200	No	—	2 $\pm$ 4.4 4 $\pm$ 4.4
E	200	Yes	2	2 $\pm$ 10 4 $\pm$ 10
F	151.9	Yes	2	2 $\pm$ 5.6 4 $\pm$ 5.6
G	130–190	No	—	1.58 $\pm$ 1.46 3.38 $\pm$ 1.46
H	300	Yes	2	2 $\pm$ 4.9 4 $\pm$ 4.9
I	300	No	—	2 $\pm$ 4.3 3 $\pm$ 4.3
J	30	No	—	2.025 $\pm$ 3.55 4.045 $\pm$ 3.55
K	300	No	—	2 $\pm$ 1.62 4 $\pm$ 1.62
L	400	No	—	1.99 $\pm$ 4.9 3.99 $\pm$ 4.9
M	250	No	—	2 $\pm$ 4.1 4 $\pm$ 4.1
N	150	No	—	2 $\pm$ 5 4 $\pm$ 5
O	200	No	—	2 $\pm$ 4.59 4 $\pm$ 4.59
IAEA	200	No	—	2 $\pm$ 5 4 $\pm$ 5
NLP	200	Yes	2	2 $\pm$ 1.3 3.98 $\pm$ 1.3

where:

- u_1 is the standard uncertainty associated with the reading of the dosimeter, irradiated by the participant laboratory. This uncertainty was calculated considering a type A and a type B component. The uncertainty type A corresponds to the standard deviation of the mean of the readings of the three dosimeters. The uncertainty type B is composed by: (a) calibration

Table 2. Average values of the measurements of the irradiated dosimeters; corresponding ratios A between the participant results ($\bar{x}$) and the declared values of Hp(10); the ratio A/B where B is the ratio of reading of the dosimeter irradiated in NPLs and the reference declared value; laboratory bias D.

Laboratory	Nominal value Hp(10) (mSv)	Net average dose (mSv) ($\bar{x}$)	A ± $U_{95\%}$ (%)	A/B ± $U_{95\%}$ (%)	Laboratory bias, D (mSv)
A	2	1.99	1.00 ± 9%	0.96 ± 10%	−0.008
	4	4.00	0.98 ± 6%	0.98 ± 8%	0.001
B	2	1.98	0.99 ± 12%	0.96 ± 14%	−0.017
	4	3.84	0.96 ± 6%	0.95 ± 8%	−0.156
C	2	2.05	1.03 ± 9%	1.00 ± 10%	0.059
	4	4.03	1.01 ± 7%	0.99 ± 9%	0.033
D	2	1.97	0.98 ± 8%	0.96 ± 10%	−0.031
	4	3.84	0.96 ± 10%	0.94 ± 10%	−0.168
E	2	2.06	1.03 ±12%	0.99 ± 13%	0.060
	4	4.12	1.03 ± 12%	1.01 ± 13%	0.123
F	2	2.02	1.01 ± 8%	0.98 ± 10%	0.019
	4	4.08	1.02 ± 8%	1.00 ± 10%	0.077
G	1.58	1.60	1.02 ± 7%	0.98 ± 9%	0.023
	3.38	3.39	1.00 ± 4%	1.03 ± 7%	0.189
H	2	2.06	1.03 ± 8%	1.00 ± 10%	0.056
	4	4.19	1.05 ± 8%	1.03 ± 10%	0.189
I	2	2.21	1.10 ± 7%	1.07 ± 9	0.207
	3	6.68	—	—	—
J	2.025	2.03	1.00 ± 7%	0.97 ± 9%	0.006
	4.053	4.05	0.99 ± 7%	0.98 ± 9%	−0.008
K	2	2.45	1.23 ± 5%	1.19 ± 8%	0.455
	4	4,14	1.04 ± 6%	1.02 ± 8%	0.144
L	2	2.12	1.06 ± 8%	1.03 ± 10%	0.127
	4	4.30	1.08 ± 8%	1.06 ± 10%	0.321
M	2	1.99	1.00 ± 7%	0.96 ± 9%	−0.009
	4	4.20	1.05 ± 8%	1.03 ± 10%	0.188
N	2	2.17	1.08 ± 16%	1.05 ± 19%	0.168
	4	4.05	1.01 ± 8%	1.00 ± 10%	0.053
O	2	2.08	1.04 ± 8%	1.01 ± 10%	0.085
	4	4.15	1.04 ± 7%	1.02 ± 9%	0.152
IAEA	2	2.02	1.01 ± 8%	0.98 ± 10%	0.017
	4	4.00	1.00 ± 8%	0.98 ± 10%	−0.002
NPL	2	2.06	1.03 ± 6%	1.00 ± 8%	0.065
	3.98	4.05	1.02 ± 6%	1.00 ± 8%	0.068

factor of the dosimeters (1%), (b) fading of the response of the dosimeters (0.10% in 45 d), (c) resolution of the reader (0.25%) and (d) stability of the reader (4.1%);

- u_2 is the standard uncertainty associated with the declared value X, informed by each participant laboratory.

The performance of the participant laboratory was also evaluated by the ratio (A) between the average value of the participant result ($\bar{x}_{\mathrm{lab}}$) and the corresponding declared value X, divided

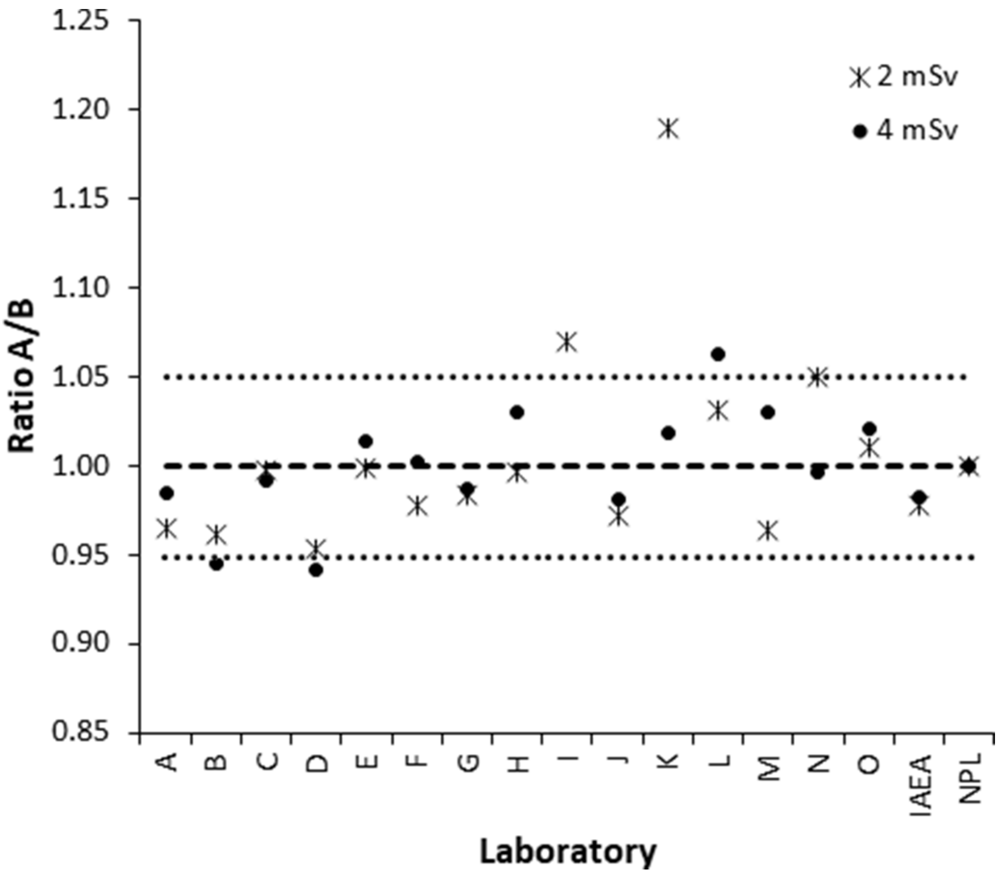

Figure 1. Values of the ratio A/B for each participant laboratory, where A is the ratio between the read of the dosimeters irradiated in the participant laboratory by the nominal value indicate by the laboratory and B is the ratio between the read of the dosimeters irradiated in the NPL laboratory by the nominal value indicate by NPL.

by the ratio (B) of the average value of the reference (NPL) result ($\bar{x}_{\mathrm{ref}}$) and the reference declared value. The combined standard uncertainty $u_{\mathrm{A/B}}$ was also calculated by equation (4).

$$u_{\mathrm{A/B}} = \sqrt{\left(\frac{1}{\mathrm{B}} \cdot u_{\mathrm{A}}\right)^2 + \left(\frac{\mathrm{A}}{\mathrm{B}} \cdot u_{\mathrm{B}}\right)^2}. \tag{4}$$

The reported relative expanded uncertainty of measurement U_{A} and $U_{\mathrm{A/B}}$ is stated as the relative standard uncertainty of measurement multiplied by the coverage factor $k = 2.00$, which for a normal distribution corresponds to a level of confidence of approximately 95%. The relative standard uncertainty of the measurement has been determined in accordance with JCGM 100:2008 [10].

4. Results and discussion

Table 1 summarizes the information on the irradiation procedures supplied by the participants. There is evidence of non-standardized conditions used, as established by ISO 4037-3:1999

[7], which was the relevant version at the time of the comparison. Two of the participating laboratories irradiated the dosimeters with a source-to-dosimeter distance outside the range of 1.50–4.0 m, where the factors for conversion from air kerma to Hp(10) were applicable. Eleven laboratories did not use the buildup PMMA plate as required by ISO 4037-3:1999. Among those that used the buildup plate, one laboratory used a PMMA plate with a thickness of 3.0 mm, which is slightly thicker than established by ISO 4037-3:1999. One laboratory irradiated the dosimeter with a Hp(10) value significantly lower than the value proposed in the protocol of the comparison exercise. This fact did not affect the current analysis of the results because the results were normalized by the dose value declared by each laboratory.

Table 2 shows the average values of the irradiated dosimeters measured at the coordinating laboratory, the associated uncertainties and the bias D between the participant result and reference value. One dosimeter irradiated by Laboratory E measured 8 mSv, strongly suggesting double irradiation. The result of this irradiation was considered an outlier and was not used to calculate the average response of the three dosimeters. The value indicated in table 2 corresponds to the average of the response of two dosimeters.

Three dosimeters irradiated in Laboratory I showed a response of 6.6 mSv, significantly higher than the value of 3.0 mSv indicated by the reference laboratory. This value also suggests double irradiation and was not used to evaluate the performance of the laboratory.

The results, presented in figure 1, show that for the dose of 2 mSv 15 laboratories (88%) have results within 5% when compared to the reference laboratory; one laboratory (I) showed a value of 7%; and only for one laboratory (K) this bias was higher than 10% (19%). The performance of all laboratories for the irradiation at an Hp(10) value of 4 mSv showed results within 5% for the reference irradiation.

5. Conclusions

The majority of the ionizing radiation metrology laboratories located in Latin America and the Caribbean region have S-Cs-137 reference irradiation services implemented; 15 SSDLs participated in this comparison exercise. The results show that the majority of these have good irradiation capabilities to irradiate personal dosimeters in the quantity Hp(10). However, some inconsistencies were evidenced in two laboratories and further action is necessary to improve the reference irradiation setup and procedures in these countries. This comparison is the first exercise of this kind in the region and it gives an indication of the basic reference irradiation capabilities. Therefore, it is further recommended to continue to perform comparison exercises for other radiation quantities and qualities.

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