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ANALYSIS OF UNCERTAINTIES IN THE MEASUREMENTS OF ABSORBED DOSE TO WATER IN A SECONDARY STANDARD DOSIMETRY LABORATORY (SSDL) ^{60}Co.

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ABSTRACT

The National Metrology Laboratory of Ionizing Radiation (LNMRI) is the laboratory designated by INMETRO in the field of Metrology of ionizing radiation and is a Secondary Standard Dosimetry Laboratory (SSDL). One of its guidelines is to maintain and disseminate LNMRI absorbed dose in water used as a national standard dosimetry in radiotherapy. For this pattern is metrologically acceptable accuracy and uncertainties should be assessed over time. The objective of this study is to analyze the uncertainties involved in determining the absorbed dose rate in water and standard uncertainty of absorbed dose calibration in water from a clinical dosimeter. The largest sources of uncertainty in determining the rate of absorbed dose in water are due to: calibration coefficient of the calibration certificate supplied by the BIPM, electrometer calibration, camber stability over time, variation of pressure and humidity, strong dependence and non-uniformity of the field. The expanded uncertainty is 0.94% for k = 2. For the calibration standard uncertainty of absorbed dose in water of a dosimeter in a clinical a major source of uncertainty is due to the absorbed dose rate in water (0.94%). The value of expanded uncertainty of calibrating a clinical dosimeter is 1.2% for k = 2.

1. INTRODUTION

The National Metrology Laboratory of Ionizing Radiation is part of the Inter-American Metrology System (SIM) as a laboratory designated by INMETRO in the field of Metrology of Ionizing Radiation and is considered a Secondary Standard Dosimetry Laboratory (SSDL) by the International Atomic Energy Agency (IAEA).

The secondary standard dosimetry laboratory (SSDL) sends its secondary standard ionization chamber (instrument usually of good quality, with respect to leakage currents and stability of short and long term), used as national standard for a primary standard laboratory (in our case the BIPM) in order to obtain the calibration in terms of air kerma and absorbed dose to water. The calibration coefficient in air kerma, Nk, and absorbed dose to water, ND,w, of the secondary ionization chamber is obtained in the standardized beam of 60 Co of the primary laboratory with its respective uncertainty. The LNMRI has a reference electrometer (calibrated separately in charge scale (nC). The ionization current measured is normalized to reference conditions of temperature, pressure and relative humidity of T=293.15 K, P=101.325 kPa and h=50%. The relative humidity must remain between 20% and 80%, during the measurements, otherwise one must apply a correction factor to h=50%.

The objective of this study is to evaluate the uncertainties of the absorbed dose to water for clinical dosimeters in ^{60}Co beams used in radiotherapy. For this Aim we divide the work in two parts: the uncertainties of the absorbed dose to water rate for the standard ionization camber used in the LNMRI and the uncertainties of the absorbed dose to water rate for clinical dosimeters.

The absorbed dose, D, is the quotient of dε by d*m*, where dε is the mean energy imparted by ionizing radiation to matter of mass d*m*, thus

$$D = d\varepsilon / dm \qquad (1)$$

The model for determining the absorbed dose rate to water [1,2] and the correspondent expression for relative uncertainty [3] is:

$$\dot{D}_{LNMRI} = N_{D,w}^{BIPM} \cdot N_{EL} \cdot I' \cdot C_T \cdot C_P \cdot \prod_i k_i \qquad (2)$$

$$\left(\frac{u_{\dot{D}_{LNMRI}}}{\dot{D}_{LNMRI}}\right)^2 = \left(\frac{u_{N_{D,w}^{BIPM}}}{N_{D,w}^{BIPM}}\right)^2 + \left(\frac{u_{N_{EL}}}{N_{EL}}\right)^2 + \left(\frac{u_{I'}}{I'}\right)^2 + \left(\frac{u_{C_T}}{C_T}\right)^2 + \left(\frac{u_{C_P}}{C_P}\right)^2 + \sum_i \left(\frac{u_{k_i}}{k_i}\right)^2 \qquad (3)$$

$N_{D,w}^{BIPM}$ is the calibration coefficient in terms of the absorbed dose to water from ionization chamber (national standard) measured at BIPM.

N_{EL} is the calibration coefficient of the electrometer.

I' is the ionization current measured in the SSDL.

C_T is the temperature correction.

C_P is the pressure correction

k_i are others factors that influence the determination of absorbed dose rate to water: humidity, position in the beam, long-term stability, energetic dependency, field uniformity and current leakage.

The model for determining the calibration coefficient in absorbed dose to water and the correspondent expression for the relative uncertainty is:

$$N_{D,w}^{U} = \left(\frac{\dot{D}_{LNMRI}}{I}\right) \cdot e^{-\frac{\Delta t}{\tau}\ln 2} \qquad (4)$$

$$\left(\frac{u_{N_{D,w}^{U}}}{N_{D,w}^{U}}\right)^2 = \left(\frac{u_{\dot{D}_{LNMRI}}}{\dot{D}_{LNMRI}}\right)^2 + \left(\frac{u_{I'}}{I'}\right)^2 + \left(\frac{u_{C_T}}{C_T}\right)^2 + \left(\frac{u_{C_P}}{C_P}\right)^2 + \left(\frac{\Delta t \ln 2}{\tau}\right)^2 \left(\frac{u_{\Delta t}}{\Delta t}\right)^2 + \left(\frac{\Delta t \ln 2}{\tau}\right)^2 \left(\frac{u_{\tau}}{\tau}\right)^2 \qquad (5)$$

Onde: $N^{U}_{D,w}$ is the calibration coefficient of dosimeter customer (electrometer + ionization chamber). Δt is the time interval between the determination of the absorbed dose rate to the water in the SSDL and calibration of the customer dosimeter.
τ is the ^{60}Co half life.

To perform the measurement of absorbed dose to water the chamber is placed on your sleeve waterproof and positioned in a phantom of dimensions 30 cm x 30 cm x 30 cm. Its axis is placed at the reference plane at a depth of 5 g/cm2 in water (Figure 1). The depth includes the window of the phantom (PMMA, 1.19 g/cm3). The mark on the glove and the camera is oriented toward the radiation beam.

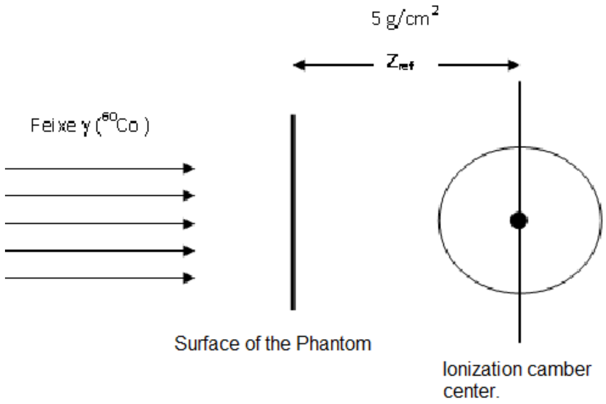

FIG 1- Arrangement for the positioning of the ionization chamber to measure the absorbed dose to water.

A reference field of 10 cm x 10 cm is set at 100 cm distance from the source and coincides with the surface of the window of the phantom (SSD arrangement). A termistor (with room reading the external irradiation) is installed in the calibration table, placed in a false ionization chamber to simulate the actual temperature to be measured, which in turn is placed inside a waterproof sleeve and immersed in the phantom. The pressure is determined by a barometer that is located in the control area of the laboratory. The distance of 100 cm from the source is obtained by a metal rod of reference.

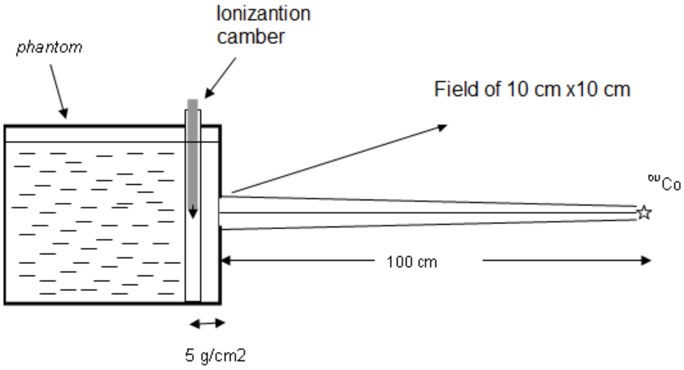

Figura 3- Positioning of the ionization chamber to measure the absorbed dose to water.

2. RESULTS

2.1 Standard uncertainty of absorbed dose to water rate

Table 3 shows the summary of the components of uncertainty for the determination of the absorbed dose rate to water in a SSDL (LNMRI). The total relative standard uncertainty is obtained by the square root of the sum of squared values of each component (equation 3).

Table 3 – Expanded uncertainty for the determination of the absorbed dose rate to water in a SSDL (LNMRI).

Uncertainty source	Value (%)	Type	Probability distribution	Divisor	Uncertainty component (%)
Calibration coefficient (BIPM)	0.3	B	Normal	1	0.3
Electrometer calibration	0.4	B	Rectangular	√3	0.231
Ionization current	0.05	A	Normal	1	0.05
Thermometer Hart 1504	0.007	B	Normal	2	0.0034
Real temperature inside chamber	0.102	B	Rectangular	√3	0.06
Air pressure	0.15	B	Normal	2	0.075
Air humidity	0.15	B	Rectangular	√3	0.087
Reference plane position	0.02	B	Rectangular	√3	0.012
Chamber position in reference plane.	0.01	A	Normal	1	0.01
Linear displacement transducer	0.027	B	Normal	2,2	0.012
Depth in water	0.013	B	Normal	2	0.007
Phantom's dilatation	0.02	B	Rectangular	√3	0.012
Chronometer NE 2546	0.01	B	Normal	2	0.005
Long-term stability	0.2	B	Normal	1	0.2
Energy dependence	0.1	B	Normal	1	0.1
Field non-uniformity	0.1	B	Normal	1	0.1
u_c(%) Relative combined uncertainty					0.47 %
U(%) Expanded standard uncertainty (95.45%)					0.94 %

The ionization chamber calibrated at the primary laboratory is used together with the electrometer in a 60Co beam in the SSDL for determining the absorbed dose rate to water. Customer dosimeters are then calibrated in this beam. The total uncertainty is the combination of the following factors:

Uncertainty in the calibration coefficient of the ionization chamber provided by the primary laboratory, BIPM, equals $\left(u_{N_{D,w}^{BIPM}} / N_{D,w}^{BIPM}\right) = 0.3\%$ k=1.

Uncertainty in the electrometer coefficient calibration equals 0.4%. Value provided by the certificate no.1215367:1232637056, issued by Keithley.

Uncertainty in ionization current in the reference chamber measured in the SSDL, equals $\left(u_{I'} / I'\right) = 0.05\%$

Uncertainty in the temperature measurement comes from two factors:

Uncertainty of the thermometer (Hard model 1504) equals 0.02 oC provided by the calibration certificate no. T0920/2008. This uncertainty in the temperature takes the value of 0.007% for k=2, according to the above model.

It is assumed that the real temperature inside the chamber does not differ from the room calibration temperature by more than 0.3oC. Assuming a rectangular distribution the estimated uncertainty is 0.06%.

The uncertainty in pressure measurement, obtained through the DPI 141 barometer, and according to the certificate n$\underline{^0}$ LIT09-LIT00-CC-0197 is of 0.15 %, for k=2.

1. Humidity: No correction for humidity is necessary if the calibration is reference to a relative humidity of 50% and is performed in a relative humidity between 20% and 80%. It is accepted that the humidity in the calibration laboratory is the same as the primary laboratory where the secondary standard chamber was calibrated. According to the ICRU 31 the correction factor of the humidity varies between 1.000 and 0.997 for the humidity between 0% and 100% at 20^{o}C and 101.325 kPa. The humidity normally found in the BIPM, during calibrations is 50%. The uncertainty due to assumption that the humidity is the same as in the BIPM and LNMRI is estimated as 0.15%.
2. Position in the beam: There are 5 types of uncertainties to consider. The entrance window of the phantom, which corresponds to a *plane of 10 cm x 10 cm,* is positioned in the Center of the reference plan 1,000 mm from the source, with the help of telescopic sight and a metal rod (pointer). The expected maximum error in setting the distance from the reference plan is 0.1mm. Assuming a rectangular distribution for the maximum difference in the absorbed dose rate to water and considering the law of inverse square distance, the uncertainty type B in the position is 0.012 %. The reference center of the ionization chamber must be located 5g/cm^2 deep in water. The beam of ^{60}Co in the LNMRI is horizontal, being necessary to consider the PMMA thickness of the entrance window of the beam. The uncertainty in this distance, according to the above model is 0.013% for k=2. The pressure of the water at the internal entrance window of the beam causes an expansion of the phantom, increasing the quantity of water in front of the chamber and must be taken into account in the positioning of the chamber. The uncertainty related to this expansion is estimated at 0.012%. Measures of displacement of the phantom are carried out through a linear displacement transducer, whose calibration certificate n$\underline{^0}$ 87 378-101, establishes the uncertainty of 0.027 %, for k=2.2. The type A uncertainty comes from the placement of the entrance window of the beam in the reference center and was evaluated equals 0.01 %.

3. The time is recorded by stopwatch NE model 2546 with an uncertainty of 0.01% in the usual interval time of measurements, for k=2, established by the certificate no. 021/08.
4. The uncertainty in the long-term stability of the whole ionization chamber and electrometer is evaluated by two consecutives measurements of absorbed dose rate to water and has a value of 0.2%.
5. The uncertainty in the energy dependency comes from the fact that the energy spectrum of the scattered photons varies for different ^{60}Co machines, due to different design of collimators. This is estimated to cause a maximum variation in the response of 0.1%.
6. The uncertainty due to a non-uniformity of the field is estimated at 0.1%.

2.2 Standard uncertainty of calibration in absorbed dose to water from a clinical dosimeter.

Table 4 shows the summary of the components of uncertainty for the determination of the calibration coefficient in absorbed dose to water in a SSDL (LNMRI). The total relative standard uncertainty is obtained by the square root of the sum of squared values of each component(equation 5).

Table 4 – Expanded uncertainty and components of the standard uncertainties of the absorbed dose to water calibration of a clinical dosimeter in a SSDL.

Uncertainty source	Value (%)	Type	Probability distribution	Divisor	Uncertainty component (%)
Water absorbed dose rate (SSDL)	0.95	B	Normal	2	0.475
Electrometer	0.5	B	Rectangular	√3	0.289
Ionization current	0.1	A	Normal	1	0.1
Thermometer Hart 1504	0.007	B	Normal	2	0.0034
Real Temperature inside chamber	0.102	B	Rectangular	√3	0.06
Air pressure	0.15	B	Normal	2	0.075
Air humidity	0.15	B	Rectangular	√3	0.087
Reference plane position	0.02	B	Rectangular	√3	0.012
Chamber position in reference plane	0.01	A	Normal	1	0.01
Linear displacement transducer	0.027	B	Normal	2,2	0.012
Depth in water	0.013	B	Normal	2	0.007
Phantom's dilatation	0.02	B	Rectangular	√3	0.012
Effect of waterproofing sleeves	0.15	B	Rectangular	√3	0.087
Chronometer NE 2546	0.01	B	Normal	2	0.005
60Co half-life (Ci=0.0432)	0.04	B	Normal	2	0.0009
Decay correction during a day (Ci=0.0432)	0.012	B	Rectangular	√3	0.0003
uc(%) Relative combined uncertainty					0.58 %
U(%) Expanded standard uncertainty (95.45%)					1.2 %

The total uncertainty is the combination of the uncertainties of position, pressure, temperature, time and humidity considered above and the following factors calculated for the customer dosimeter.

The estimation of the type B uncertainty of the 60Co half life is 0.04% (k=2) as referenced in Lagoutine et al (1982), Table of Radionucleides. Assuming a normal distribution and considering the multiplicative factor present in the expansion of the above uncertainty, where Δt equals 120 days, we have an uncertainty of 0.0009%.

During a day the absorbed dose rate to water is corrected due the decay only once, implying that the maximum uncertainty in Δt is of eight hours. This affects the signal at 0.012%. Assuming a uniform rectangular distribution and using the multiplicative factor present in the above uncertainty expansion, where Δt equals 120 days, that the maximum time period between two measurements of the absorbed dose rate to water, one obtains an uncertainty of 0.0003%.

The uncertainty in the reference instrument of the customer is assumed being equals 0.5%.
The uncertainty in the measurement of the customer instrument current is equals 0.1%.
A waterproof sleeve is used to put in place the reference Center of the ionization chamber, even when it is waterproof. The uncertainty of the absorbed dose rate to the water due to use of the sleeve is estimated in 0.5%.

3. CONCLUSION

The largest sources of uncertainty in determining the rate of absorbed dose to water are due to: calibration coefficient of the calibration certificate supplied by the BIPM, electrometer calibration, camber stability over time, variation of pressure and humidity, strong dependence and non-uniformity of the field. The expanded uncertainty is 0.94% for k = 2. For the calibration standard uncertainty of absorbed dose in water of a dosimeter in a clinical SSDL, the largest source of uncertainty is due to the absorbed dose rate in water (0.94%). The value of expanded uncertainty of calibrating a clinical dosimeter is 1.2% for k = 2. These low values of expanded uncertainty corroborate all the effort made by LNMRI to maintain the standard of absorbed dose in water with the best possible accuracy.

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REFERENCE

[1] International Atomic Energy Agency. Absorbed dose determination in external beam radiotherapy. Technical Report Series No. 398. Vienna: IAEA, 2000.

[2] International Atomic Energy Agency. Calibration of Reference Dosimeters for External Beam Radiotherapy. Technical Report Series No. 469. Vienna: IAEA, 2009.

[3] International Atomic Energy Agency. Measurement Uncertainty . TECDOC 1585. Vienna: IAEA, 2008.