SIM.RI(I)K1-K4: Technical Protocol for Comparison of Air Kerma and Absorbed Dose to Water in ^{60}Co Fields

John Paul Archambault, Brad Downton, Malcolm McEwen
National Research Council Canada

July 9, 2019

1 Introduction

A comparison of the standards for air kerma and absorbed dose to water in ^{60}Co fields will occur between seven laboratories within the Systema Interamericano de Metrologia (SIM). The comparison will use three transfer ionization chambers, which will be circulated among the laboratories. Two of the laboratories, the National Research Council Canada (NRC) and the National Institute of Standards and Technology (NIST), maintain primary standards for both air kerma and absorbed dose to water and provide a link to the key comparison data base (KCDB) [1] of the Mutual Recognition Arrangement of the International Committee for Weights and Measures (CIPM MRA) [2]. This comparison will update previous SIM comparisons of air kerma [3] and absorbed dose to water [4].

This protocol will outline the aspects of the comparison. A list of the participants, along with contact information for each laboratory is provided in section 2. An outline of the procedures for the comparison, including definitions, descriptions of the equipment, reference conditions, an uncertainty budget to consider and a guide to submitting results are given in section 3. Section 6 provides the schedule for the measurements. A complete checklist of the equipment being sent is given in section 7.

2 Participants

A list of the participants is provided in table 1, along with contact personnel for each of the laboratories. Of the seven participants, two labs (NIST and NRC) maintain primary standards for both air kerma and absorbed dose to water. The other labs maintain secondary standards and are traceable to primary laboratories, the BIPM or IAEA.

Table 1: List of participants and technical contacts

Institute	Country	Contact	email
CCHEN	Chile	Fernando Ortega	fernando.ortega@cchen.cl
CNEA	Argentina	Amalia Stefanic	stefanic@cae.cnea.gov.ar
ININ	Mexico	Daniel de la Cruz	daniel.delacruz@inin.gob.mx
LNMRI-IRD	Brazil	Karla Patrao	karla@ird.goc.br
MIEM	Uruguay	Guillermo Balay	Guillermo.Balay@miem.gub.uy
NIST	United States	Ronaldo Minniti	ronnie.minniti@nist.gov
NRC (pilot)	Canada	Ernesto Mainegra-Hing	Ernesto.Mainegra-Hing@nrc-cnrc.gc.ca

3 Materials and Methods

1. **Calibration Coefficients:** Indirect comparisons of the air kerma and absorbed dose to water standards will be completed by measuring the calibration coefficients of ionization chambers and comparing the results of the individual labs to that of NRC. The calibration coefficients of the chambers for air kerma, N_K, and absorbed does to water, $N_{D,w}$, are defined as

$$N_K = \dot{K}_a/I \tag{1}$$

$$N_{D,w} = \dot{D}_w/I. \tag{2}$$

   In the above equations, I is the current measured due to positive ions produced in the gas cavity due to an air kerma rate of $\dot{K}_a$ or absorbed dose to water rate of $\dot{D}_w$. The current in eqs. (1) and (2) is corrected for the relevant influential quantities. (see section 4 for details).

2. **Transfer Chambers:** Three ionization chambers, provided by the NRC, will be used as the transfer chambers. They will consist of two Exradin A12 (one Exradin A12 and one Exradin A12S) and a single PTW TN30013. All three are waterproof Farmer-type ion chambers and will be supplied along with their respective build-up caps (required for air kerma measurements). Each laboratory will be required to provide measurement results for at least two of the supplied chambers, preferably the Exradin A12 and PTW TN30013. A laboratory may measure all three chambers, provided it does not compromise the calibration schedule outlined in section 6.2 of this protocol. In addition to the three transfer chambers, a Standard Imaging Supermax electrometer will also be supplied. It is strongly encouraged that each participant also perform measurements with their own electrometer in addition to the one supplied. Although only the results using the supplied electrometer will be analyzed, the measurements with the laboratory's electrometer may be used as a consistency check. It may also be required should a failure of the Supermax electrometer occur. A summary of the nominal characteristics for the transfer chambers and their build-up caps is provided in the table below.

Chamber	Serial Number	Sensitive Volume [cm^3]	Thimble Diameter [mm]	Cap Diameter [mm]	Electrode Material	Wall Material
PTW TN30013	010846	0.6	6.9	16.4	Al	graphite/PMMA
Exradin A12S	XZ072134	0.24	7.1	12.7	C-552 plastic	C-552 plastic
Exradin A12	XA082313	0.64	7.1	12.7	C-552 plastic	C-552 plastic

4 Measurement Procedures

1. **Reference Conditions:** The calibration coefficient for the transfer chamber should be given in terms of air kerma per charge and absorbed dose to water per charge, in units of Gy/nC and refer to standard conditions of air temperature (T), pressure (P) and relative humidity (h) of $\mathrm{T} = 295.15\ \mathrm{K}, \mathrm{P} = 1013.25\ \mathrm{kPa}$ and $\mathrm{h} = 15\%$-75%, respectively.

2. **Chamber Positioning:** The chambers will be positioned such that the stems are perpendicular to the axis of the beam of radiation with the appropriate markings facing the source. It is recommended to set the Point of Measurement (POM) at the centre of the chamber collecting volume (in all directions) along the beam axis. The reference points along the central axis of the chambers are 12.9 mm, 5.79 mm and 13.0 mm from the thimble tip for the Exradin A12, Exradin A12S and PTW chambers (respectively).

   Air Kerma - The Source to Chamber Distance (SCD) will be set at the distance that each laboratory uses for dissemination of their standards, such that the centre of collecting volume is at a distance between 80 cm and 100 cm, where the field size is 10 cm x 10 cm.
   Absorbed Dose to Water - The water phantom is to be placed with a Source to Surface Distance (SSD) the laboratory uses for dissemination of their standard, such that the surface of the water is between 80 cm and 100 cm, where the field size is 10 cm x 10 cm at either the surface of the water or the specified measurement depth. The water-proof chamber is to be positioned with the centre of its collecting volume at a laboratory standard depth between 5 cm and 10 cm from the surface of the water along the beam axis. The SSD, measurement depth, field size (including whether at the surface of the water or measurement depth) and beam orientation (vertical or horizontal) are to be included in the report.

3. **Electrometer Settings:** The preference for the comparison is to measure current using the supplied electrometer, with the settings provided in the table below. The Standard Imaging SuperMax instrument is a current-sensing device which provides charge measurements by integrating the measured current over time using its internal timer. The SuperMax timer has not been calibrated, so it is not recommended to be used. However, a laboratory can perform their measurements by collecting charge if they wish but these must be done using a laboratory shutter/source transit timing system, and the measured currents are to be summarized and provided in the report to the pilot laboratory. The additional uncertainty associated with beam on/off should be included in the report. For the default current measurement system, it is recommended that a series of current measurements be recorded with the ^{60}Co irradiator set to a long irradiation time.

Bias Voltage	Channel	Mode	Range	Measured Current
-300V	1	Current	Low High	<500 pA >500 pA

It is recommended that the electrometer be powered ON for at least 30 minutes before use.

4. **Settling Time:** It is recommended to pre-irradiate the chambers for a minimum of 30 minutes with the electrometer bias set as described in item 3 prior to performing measurements in order to avoid any settling effects.

5. **Leakage Current:** Current is to be measured in the absence of any source for a minimum of five minutes to estimate the leakage/background current.

6. **Radial Non-uniformity:** A correction should be applied to the ionization current due to the radial non-uniformity of the beam over the cross-section of the chambers.

7. **Ion-recombination, Polarity:** The reporting of ion-recombination and polarity corrections is not required.

5 Reporting Results

1. **Calibration Coefficients:** The values to be reported are summarized in the tables below. NRC will provide each participant with a package of forms, in MS Excel format, which are to be completed with as much detail as possible and submitted along with the lab report.

Air Kerma			
Quantity	Units	Value	Uncertainty ($k = 2$)
I	nA		
$\dot{K}_a$	Gy		
N_K	Gy/nC		

Absorbed Dose to Water			
Quantity	Units	Value	Uncertainty ($k = 2$)
I	nA		
$\dot{D}_w$	Gy		
$N_{D,w}$	Gy/nC		

2. **Uncertainties:** Uncertainty budget components are summarized in the tables below. Space to record these values is included in the MS Excel package. Participants should fill in the standard uncertainties associated with their measurements accordingly. Other sources of uncertainty should be included if necessary. *NOTE: Stability of the transfer chambers used will be included in the final report provided by NRC.*

Air Kerma		
Source of Uncertainty (Air Kerma)	$100s_i$	$100u_i$
air kerma rate		
ionization current of the transfer instrument		
distance and orientation		
correction factors (temperature and pressure)		
other (explain)		
Relative Uncertainties of N_K		
quadratic summation		
combined uncertainy		

Absorbed Dose to Water		
Source of Uncertainty (Absorbed Dose)	$100s_i$	$100u_i$
absorbed dose to water		
ionization current of the transfer instrument		
distance and orientation		
correction factors (temperature and pressure)		
depth in water		
other (explain)		
Relative Uncertainties of $N_{D,w}$		
quadratic summation		
combined uncertainy		

6 Schedule

6.1 Shipping

A representation of the schedule for measurements at the different laboratories is provided in fig. 1. The number located in the parenthesis indicates the sequence for shipping the equipment. For example, the equipment will be shipped to NIST first, followed by ININ, etc. To monitor the stability of the chambers, the equipment will be returned to NRC after measurements have been completed at each lab. This should minimize the impact of importing or exporting issues on the participants.

Each lab will have two weeks to perform the measurements once the equipment has arrived. NRC will cover the cost of shipping to the laboratories, but each lab is asked to cover the costs associated with the return of the equipment to NRC. For simplicity, it is recommended that each lab use Fedex to ship the equipment. The NRC shipping contact (included below) should be informed when the equipment has arrived at the participant's lab and when it departs. When returning the equipment to NRC, please provide the associated tracking number.

The shipping address to use when sending the equipment to NRC is the following:

NRC Shipping Contact Information
Brad Downton
brad.downton@nrc-cnrc.gc.ca
1-613-993-2715 ext. 245

NRC Shipping Address
National Research Council of Canada
NRC Metrology
Attention: Brad Downton
1200 Montreal Road, Building M35
Ottawa, ON, Canada
K1A 0R6

6.2 Schedule for Reporting Results

Results should be submitted to the NRC within one month of shipping the equipment back to NRC, and should include the laboratories report along with a completed copy of the MS Excel forms provided.

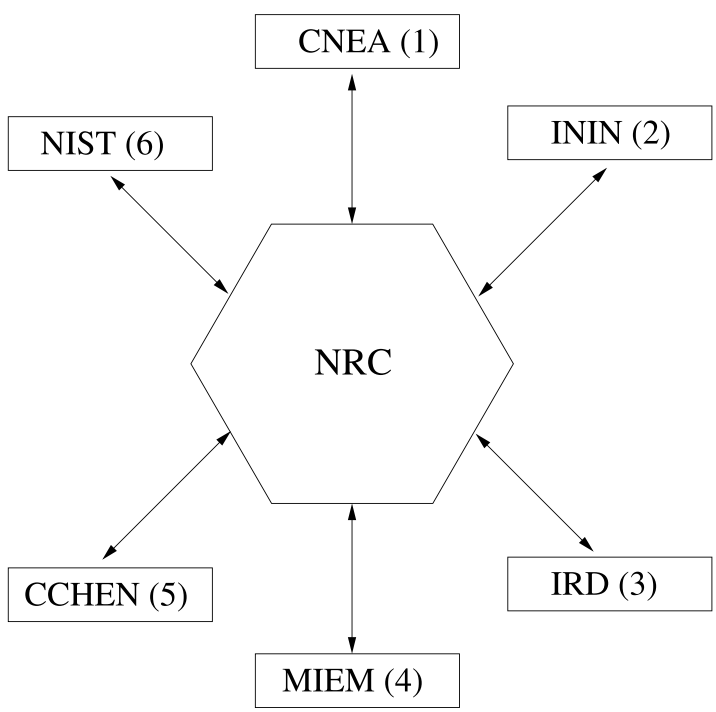

Figure 1: Schedule for shipment of equipment

6.3 Start Date

The proposed start date is mid-July 2019, with completion of all measurements and reporting of all results to be completed within six months of the start date.

7 List of Package Contents

The list of contents to be shipped is provided in the table below. A table will be provided in the MS Excel package which can be used to record the receipt and shipment of each item. Participants should verify that all the contents are accounted for upon arrival and departure of the shipment by marking the relevant field in the spreadsheet, beside each of the contents.

Qty	Item	In	Out
1	PTW TN30013 Ionization Chamber, S/N 010846 (with build-up cap)		
1	Exradin A12S Ionization Chamber S/N XZ072134 (with build-up cap)		
1	Exradin A12 Ionization Chamber S/N A082303 (with build-up cap)		
1	Standard Imaging Supermax electrometer, S/N P133122		
1	Triaxial Extension Cable with Two-lug Bayonet Style Terminations (10 m)		
3	Triaxial Adapters (Male TRB-Female TNC, Male TNC-Female TRB, Two-lug Female TRB-Female TRB)		
1	Power Cable (for Supermax Electrometer - two pieces)		

8 References

[1] BIPM, (2002), The BIPM key comparison database. http://kcdb.bipm.org/.

[2] BIPM, (1999), Mutual recognition of national measurement standards and of calibration and measurement certificates issued by national metrology institutes.
http://www.bipm.org/utils/en/pdf/CIPM-MRA-2003.pdf.

[3] Ross, C.K, Shortt, K.R. Final Report of the SIM ^{60}Co Air-Kerma Comparison.
KCDB Entry SIM.RI(I).K1. May 2008.

[4] Ross, C.K, Shortt, K.R. Final Report of the SIM ^{60}Co Absorbed-Dose-to-Water Comparison.
KCDB Entry SIM.RI(I).K4. May 2008.