Technical protocol of APMP key comparison for the measurement of Cs-137 gamma-ray air kerma (APMP.RI(I)-K5)

1. Introduction

This comparison of high intensity Cs-137 gamma-ray air kerma measurements is agreed to be undertaken in the APMP TCRI to establish the degrees of equivalence. A total of 10 laboratories are scheduled to participate in the comparison, and the Institute of Nuclear Energy Research (INER) is the pilot laboratory.

In this comparison, two transfer chambers will be circulated using the circulation scheme shown in Figure 1 between INER and the other participants. NMIJ, NIM and KRISS are the link laboratories to the Key Comparison Reference Value (KCRV).

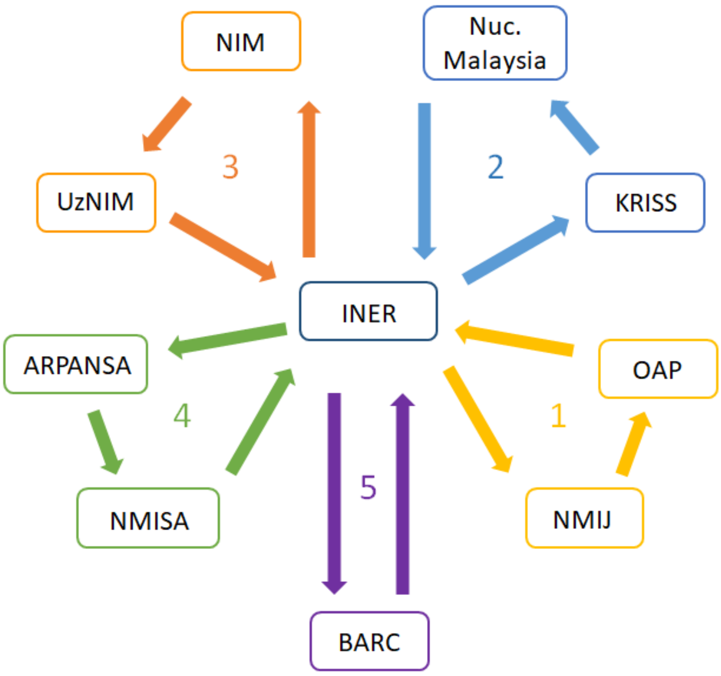

Figure 1. Circulation scheme of the comparison

2. Participants

The 10 participants in the comparison are listed in Table 1.

Table 1. Participants in the comparison

Institute*	**Affiliation**	**Contact person (e-mail)**
ARPANSA	Australia	Chris Oliver (chris.oliver@arpansa.gov.au)
BARC	India	Sunil K. Singh (bhusunil@barc.gov.in) Smt. Sneha C. (headrss@barc.gov.in)
INER	Chinese Taipei	Yu-Tien Tsai (candytsai@iner.gov.tw)
KRISS	Korea	Yi Chul-Young (cyyi@kriss.re.kr)
NIM	China	Dehong LI (lideh2000cn@163.com)
NMIJ	Japan	Junya Ishii (junya-ishii@aist.go.jp)
NMISA	South Africa	Sibusiso Jozela (sjozela@nmisa.org)
Nuc. Malaysia	Malaysia	Mohd Taufik Dolah (taufik@nm.gov.my)
OAP	Thailand	Vithit Pungkun (vithit.p@oap.go.th)
UzNIM	Uzbekistan	Azamat Taubaldiev (t.azamat@nim.uz) (azamat.taubaldiev@gmail.com)

* Listed in alphabetical order.

3. Transfer chambers

Two transfer chambers, Exradin A5 and PTW 23361, are selected to provide redundancy. If one chamber becomes unusable during the comparison, the comparison will continue using the remaining chamber. A brief description of the transfer chambers is given in Table 2.

Exradin A5 is a spherical ionization chamber with a nominal volume of 100 cm^3. The wall material is C552 plastic with a thickness of 3 mm. The outer diameter and inner diameter of the chamber are 63.1 mm and 57.2 mm, respectively.

PTW 23361 is a cylindrical ionization chamber with a nominal volume of 30 cm^3. The wall material is PMMA and graphite with a thickness of 1 mm. The inner dimensions of the cavity are 31 mm in diameter and 51 mm in length. The chamber has a 3 mm-thickness PMMA buildup cap.

Photos of the transfer chambers are given in the appendix.

Table 2. Description of the transfer chambers

IC Model	**Serial #**	**Chamber geometry**	**Nominal sensitive volume (cm^3)**	**Cavity dimensions**	**Voltage (V)***	**Cable connection**
Exradin A5	XY242272	Spherical IC	100	Diameter 57.2 mm	-800	TNC connector
PTW 23361	00838	Cylindrical IC	30	Diameter 31 mm Length 51 mm	-300	BNC connector

* Negative voltage is applied to the chamber wall with respect to the central electrode being held at ground potential.

4. Reference conditions, measurement procedure and report of the results

The relevant data from ICRU90[1] should be used for the primary standards from the participants in the comparison and for the primary standards against which the secondary standards have been calibrated.

The geometrical center of the Exradin A5 and the reference point of the PTW 23361 (which is 27 mm behind the chamber tip along the central axis of the cylinder) shall be placed at the reference point of the measurement. The chambers should be positioned with their stems perpendicular to the beam axis and with the red alignment marks on the chamber stems (see Figures 2 and 3) pointing towards the radiation source. The source-to-chamber distance depends on the size of the cross-sectional area of the chambers. Each participant is responsible for ensuring that the radiation field is large enough for the chamber volumes to be fully covered by the primary beam. The radiation field should be circular (at least 10 cm diameter) or rectangular with a field size of at least 10 cm × 10 cm, which is defined by the 50 % value of the beam intensity at the center. The beam homogeneity should be 5 % or better. In the measurement, the ionization current of the PTW 23361 chamber should be measured with the buildup cap fitted. No additional buildup cap is required for the Exradin A5 chamber.

For the transfer chambers to equilibrate with the ambient atmosphere, they should be placed in each laboratory at least 12 hours before the measurements take place. The electrometer and high voltage supply should be warmed up for at least 2 hours. After the signal cable is connected to the electrometer and the high voltage is applied to the transfer chambers, a minimum of 1 hour stabilization and a minimum of 10 minutes pre-irradiation before the measurement are suggested for the whole ionization current measurement system.

At least 10 repeated measurements should be taken to form a set of measurements for each transfer chamber. The measured ionization current should be normalized to the reference environmental conditions of 293.15 K and 101.325 kPa. The relative humidity of the environment should be between 20% and 80%, otherwise a correction to *h* = 50% should be applied. Before and after measurement of the Cs-137 ionization current, a background and leakage current should be measured. The net ionization current is obtained by subtracting the average background and leakage current where it is typically in the order of 0.1% of the ionization current.

Generally, the participants do not need to correct for the ion recombination. The pilot laboratory will evaluate the effects based on beam parameters of the participating laboratories, and the results will be included in the uncertainty evaluation of the comparison. However, if the evaluation from the participants shows that the recombination correction is greater than 0.2%, ion recombination should be corrected according to the two-voltage method:

$$k_{sat} = \frac{1 - (V_H/V_L)^2}{M_{Hav}/M_{Lav} - (V_H/V_L)^2}$$

where k_{sat} is the ion recombination correction factor,

V_H is the operating voltage (V),

V_L is a lower voltage [here: $V_L = V_H/3$] (V),

M_{Hav} is the average electrometer reading with the chamber operated at V_H (A),

M_{Lav} is the average electrometer reading with the chamber operated at V_L (A).

The temperature dependence of the cavity ionization chamber response[2] has to be considered. For the PTW 23361 chamber, the temperature effect is negligible since the thermal expansion of graphite near room temperature is within 0.01%. For the Exradin A5 chamber, to account for temperature-dependent effects such as thermal expansion and potential structural loosening, a temperature-dependent uncertainty should be added. This uncertainty is estimated to be one tenth of the net amount of the cavity gas density correction caused by the difference between the measurement temperature and the reference temperature. The temperature-dependent uncertainty (u_{temp}) can be evaluated as:

$$u_{temp} = 0.1 \times \max\left|\frac{273.15 + T_{mea,i}}{273.15 + T_{ref}} - 1\right|$$

where $T_{mea,i}$ is the temperature for the *i*-th measurement (in ℃),

T_{ref} is the reference temperature (in ℃).

Differences in air attenuation due to air density variations should also be taken into account. An air attenuation uncertainty of 0.1% should be added, as this effect is typically less than 0.1% near room temperature [3].

The air kerma calibration coefficient of the transfer chambers to be evaluated for the participating laboratories is:

$$N_K = (\dot{K}/I)\prod_i k_i$$

where N_K is the air kerma calibration coefficient (Gy/C),

$\dot{K}$ is the air kerma rate (Gy/s),

I is the net ionization current (A),

k_i is the *i*-th correction factor.

The calibration coefficient of each transfer chamber shall be measured at negative polarity only. The corresponding uncertainty should be evaluated according to the ISO guidance[4].

A Microsoft Excel spreadsheet for reporting results of the measurements will be sent to the participants as a template. The information to be described by the participants for each transfer chamber measurement is as follows:

A. Cs-137 source and irradiator

- Manufacturer / model and serial number of the irradiator
- Manufacturer / model and serial number of the source
- Nominal activity and reference date
- Source dimension, capsule dimension & material (if available)
- Collimated beam or panoramic beam
- Beam modifier (if any; e.g., additional filters and attenuators; otherwise

state “None”)

- Declared air kerma rate at 1 m and reference date
- Half-life value and its reference used for decay correction
- Source-to-chamber distance (SCD) and field size at the SCD

B. Electrometer
   - Manufacturer & model
   - Operation mode (charge or current)
   - Traceability (laboratory name and certification number)

C. Characteristics of the standard
   - Primary or secondary standard
   - Manufacturer, model & serial number
   - Traceability (laboratory name and certification number)
   - Operating voltage
   - Measurement date
   - Measurement distance
   - Air kerma rate at SCD and reference date

D. Measurement procedure
   - Thermal equilibrium time with the environment after setup at the participant's site
   - Date and time of chamber bias voltage setting (yyyy-mm-dd hh:mm)
   - Duration of the pre-irradiation
   - Date and time of start of the measurement (yyyy-mm-dd hh:mm)
   - Date and time of completion of the measurement (yyyy-mm-dd hh:mm)
   - Number of repeat measurements

E. Measurement results
   - Temperature range during the measurement
   - Atmospheric pressure range during the measurement
   - Relative humidity range during the measurement
   - Air kerma rate at SCD during the comparison measurement
   - Background and leakage current
   - Net ionization current (background and leakage current subtracted)
   - Ion recombination correction factor (if any; otherwise state “None”)

- Calibration coefficient (Gy/C)

F. Uncertainty budget in % (k = 1)

5. Comparison structure and schedule

The transfer chambers will be circulated as shown in Figure 1 between INER and the other participants. Each participant will be responsible for the payment of the transport from their own institute to the next participant's institute (including the export/import custom duties).

It is recommended to take photographs of the transfer chambers when receiving the transfer chambers. The transfer chambers should not stay at the participants' laboratories for more than 3 weeks. And the results are expected to be submitted to the pilot laboratory within 6 weeks of calibration.

INER will carry out chamber constancy checks after every one to two participants' calibrations by re-calibrating the transfer chambers (Figure 1). These data will be the basis for the uncertainty estimation of the chamber stability.

The comparison is scheduled to commence on 03-Aug-2026 and expected to be completed on 27-Dec-2027. In order to avoid successive delays of the comparison schedule, compliance with the itinerary of the shipment is advisable even if measurements at the participating laboratory are incomplete. Feasible ways to deal with this situation will be sought after completion of all the scheduled measurements.

Please see Table 3 for the proposed schedule.

Table 3. Proposed schedule of the APMP.RI(I)-K5 comparison

Participant	Measurement period at the participant's laboratory	Date of the chambers leaving the participant for shipment to the next participant
INER	03-Aug-2026	24-Aug-2026
NMIJ	07-Sep-2026	28-Sep-2026
OAP	12-Oct-2026	02-Nov-2026
INER	16-Nov-2026	07-Dec-2026
KRISS	21-Dec-2026	11-Jan-2027
Nuc. Malaysia	25-Jan-2027	15-Feb-2027
INER	01-Mar-2027	22-Mar-2027
NIM	05-Apr-2027	26-Apr-2027
UzNIM	10-May-2027	31-May-2027
INER	14-Jun-2027	05-Jul-2027
ARPANSA	19-Jul-2027	09-Aug-2027
NMISA	23-Aug-2027	13-Sep-2027
INER	27-Sep-2027	18-Oct-2027
BARC	01-Nov-2027	22-Nov-2027
INER	06-Dec-2027	27-Dec-2027

6. Evaluation and publication of the results

After the comparison is completed, the pilot laboratory will evaluate the comparison by analyzing the results submitted by the participants. The Key Comparison Reference Value (KCRV) is the CIPM key comparison reference value. Each link laboratory has an established relationship to the KCRV through the corresponding key comparison. For each participant, the degrees of equivalence with respect to the KCRV will be evaluated using the results from each of the three link laboratories. The set of degrees of equivalence will then be combined in accordance with the procedure in the reference[5]. Each transfer chamber will be analyzed independently. The results obtained using the two transfer chambers will then be combined following the procedure for multiple transfer instruments described in the reference[5]. Further information will be provided in the Draft A report.

The pilot laboratory will prepare the Draft A report of the comparison and circulate the report among participants for comments and corrections. Once approved by all the participants, the revised version Draft B report will be submitted to the APMP TC chair and the KCWG of CCRI(I). Once approved, the Draft B report will be submitted to the BIPM for inclusion of the degrees of equivalence presented in the report to the KCDB.

References

1. International Commission on Radiation Units and Measurements (ICRU), Key Data for Ionizing-Radiation Dosimetry: Measurement Standards and Applications, ICRU Report 90 (2016).
2. Chul-Young Yi and Hyun-Moon Kim, Temperature dependence of cavity ionization chamber response, Metrologia 50 (2013) 146–152.
3. Chul-Young Yi, Yoon Ho Kim, In Jung Kim, Jong In Park and Young Min Seong, Measurement of average mass attenuation coefficient of air for ^{137}Cs gamma-ray irradiation beam, Metrologia 61 (2024) 065005 (7pp).
4. International Organization of Standard (ISO), Guide to the expression of uncertainty in measurement, 3rd ed., Switzerland (2008).
5. D. T. Burns and P. J. Allisy-Roberts, The evaluation of degrees of equivalence in regional dosimetry comparisons, CCRI(I)/07-04 (2007).

Appendix – Transfer chambers

Figure 2. The spherical Exradin A5 chamber.

Figure 3. The cylindrical PTW 23361 chamber.