Draft protocol of APMP.RI(I)-K8
Reference air kerma rate for HDR Ir-192 brachytherapy sources

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1. Introduction

The objective of this comparison is to establish the degrees of equivalence between national standards or methods for determining the reference air kerma rate for HDR 192Ir brachytherapy sources (RAKR or $\dot{K}_R$). For this purpose, it is proposed to use two well-type chambers as the transfer instruments. The NMIJ/AIST is the pilot laboratory and the NMIJ/AIST and the NRC are the linking laboratories to the BIPM.RI(I)-K8 key comparison. This protocol is based on the BIPM.RI(I)-K8 protocol document [1].

2. Participants

The participants are listed in Table 1.

Table 1. List of participants in the comparison.

Institute	Country	Contact person	E-mail
PTKMR - BATAN	Indonesia	C. Tuti Budiantari	ptkmr@batan.go.id
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KRISS	Korea	Chul-Young Yi	cyyi@kriss.re.kr
NMISA	South Africa	Sonwabile Arthur Ngcezu	sangcezu@nmisa.org
Malaysian Nuclear Agency	Malaysia	Mohd Taufik Dolah	taufik@nm.gov.my
NMIJ	Japan	Tadahiro Kurosawa Norio Saito	tadahiro-kurosawa@aist.go.jp norio.saito@aist.go.jp
NRC	Canada	Malcolm McEwen	Malcolm.McEwen@nrc-cnrc.gc.ca

IAEA	Int. Org.	Paula Toroi	P.Toroi@iaea.org

3. Comparison procedure

3.1 Transfer chambers

Two well-type ionization chambers (Standard Imaging, HDR 1000 Plus) are to be used as the transfer standards for the comparison, as listed in Table 2. The signal connection of the chambers is a tri-axial BNT plug. An adapter of the plug (Triax BNC-F to Triax TNC-M/F Adapter 323-324) is also provided. The NMIJ will also send a source holder with the diameter 2.2 mm (Holder HDR 1000 – part number 90008) for the guide tube. If this diameter is not compatible with the participant's Ir-192 source type, then the participants shall use their own holder. This should be noted in the report sent to the host laboratory. A system to measure the current from the chambers is NOT provided. Participants should use their own charge/current measuring system (electrometer).

Table 2. Characteristics of well chamber HDR 1000

Characteristics	Nominal Value
Height of the chamber	15.6 cm
Diameter of the chamber	10.2cm
Insert height	12.1 cm
Insert Diameter	3.5 cm
Active volume	245 cm^3
Potential of HV electrode with respect to collecting Electrode	-300 V

3.2 Reference conditions

The temperature, pressure and humidity at the time of the measurements should be reported; the measurements must be normalized to the reference environmental conditions of 20 °C and 101.325 kPa. The reference relative humidity is 50 %. No correction for humidity is required if the value is in the range 20 % < RH < 80 %.

3.3 ^{192}Ir source

Each participant may choose their usual source construction/type and appropriate activity. However, as the transfer chamber responses are dependent on the ^{192}Ir source design, the source reference code, manufacturer and apparent activity should be reported.

The NMIJ measures the calibration coefficients of the transfer chambers for the sources provided from MicroSelectron mHDR-V2 and Varian Varisource VS2000. It is advisable to use sources by MicroSelectron mHDR-V2 or Varian Varisource VS2000.

3.4 Measurements

The well-chamber response depends on the source position inside the chamber and therefore the calibration coefficient should be obtained for the source inserted to the point of maximum chamber response (sweet spot). The HDR-1000 well chamber has its nominal maximum response at about 50 mm from the bottom of the chamber insert. Each NMI shall measure this position of maximum chamber response (by stepping the brachytherapy source through the well chamber) and the position of this point should be reported in the comparison report as the distance (in mm) from the center of the ^{192}Ir source to the tip of the plastic catheter. The warm-up time for an electrometer should be more than 12 hours and the chamber should be connected to the electrometer more than 1 hour before measurements. The pre-irradiation of the chamber with around 5 minutes is considered to be appropriate. To ensure air communication, it should be verified that the vent hole on the chamber is not blocked. It should be allowed sufficient time for the well chamber to achieve equilibrium with laboratory conditions (temperature, humidity).

To estimate the sensitivity to source positioning, it is recommended to make three sets of measurements, one for the sweet spot and two for the sweet spot plus or minus 0.5 mm. Each set should have three series of ten measurements, each measurement with an integration time of 60 seconds. Ideally, the whole process (determination of sweet spot and measurements at three positions) should be repeated. It is advisable to place the well chamber on a low-scatter support at a distance of 1 meter or more from any wall and from the floor of the calibration room [2].

3.5 Calibration coefficient

Participants should calibrate the transfer chambers in term of the reference air kerma rate using their ^{192}Ir source. After the sweet-spot position has been identified and verified as indicated in section 3.4, the ionization current should be measured by the participant's electrometer and it is normalized to the reference temperature and pressure, corrected for decay to the reference date, and corrected for ion recombination depending on the ionization current actually measured. The calibration coefficient $N_{K,\mathrm{NMI}}$ for the well-type chamber is expressed as

$$N_{K,\mathrm{NMI}} = \frac{\dot{K}_{\mathrm{R,NMI}}}{(M_{\mathrm{raw}} - M_{leak}) \cdot k_{\mathrm{ele}} \cdot k_{\mathrm{ion}} \cdot k_{\mathrm{dec}} \cdot k_{PT}} \quad (1)$$

where:

$\dot{K}_{\mathrm{R,NMI}}$ is the RAKR determined by the NMI with the reference standard/method,

M_{raw} is the raw current measured by the NMI without any correction,

M_{leak} is the leakage or background current measurement,

k_{ele} is the calibration coefficient of participant's electrometer, k_{ion} is the correction factor for ion recombination in the well chamber, which is normally estimated by measuring the current with HV of 150 V and 300 V,

k_{dec} is the correction factor for radioactive decay of the source, and

k_{PT} is the correction factor for atmospheric conditions.

No correction is required for any polarity effect as long as polarity of the collecting electrode is as indicated in Table 2.

k_{ion} is calculated using the following equation.

$$k_{\mathrm{ion}} = \frac{(V_1/V_2)^2 - 1}{(V_1/V_2)^2 - M_1/M_2} \quad (2)$$

where:

V_1 is Apply voltage for normal operation

V_2 is Reduced apply voltage for ion recombination measurement

M_1 is Measured current at V_1

M_2 is Measured current at V_2.

3.6 Proposed schedule for the comparison

The comparison is performed in a circular manner, as illustrated in Figure 1 and Table 3. Each participant shall pay the cost for shipping to the next participant. The chambers should stay at the participants' site for **no longer than 1 week.** The NMIJ measures the calibration coefficients of the chambers before and after the comparison as a check on the stability. The circular path requires a fast turnaround for each laboratory to minimize the effect of any drift in transfer chamber response. The NMIJ and the NRC perform a preliminary bilateral comparison for a stability test of the chambers before the comparison starts.

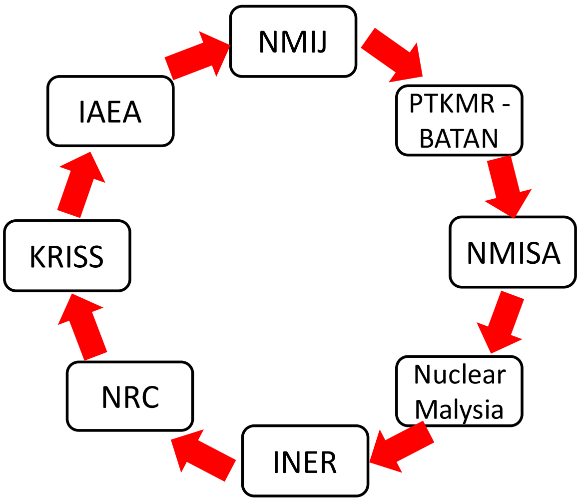

Figure 1. Comparison shape.

Table 3. Proposed schedule for the comparison.

Institute	Receive chambers	Measurement	Send chambers
NMIJ*		September, 2016	October 15, 2016
NRC*	October 25, 2016	October– November, 2016	November 10, 2016
NMIJ	November 20, 2016	December, 2016	May 15, 2017
PTKMR - BATAN	May 26, 2017	May 29 – June 2, 2017	June 5, 2017
NMISA	June 16, 2017	June 19 – June 23,	June 26, 2017

		2017	
Nuclear Malaysia	July 7, 2017	July 10 – July 14, 2017	July 17, 2017
INER	July 28, 2017	July 31 – August 4, 2017	August 7, 2017
NRC	August 18, 2017	August 21 – August 25, 2017	August 28, 2017
KRISS	September 8, 2017	September 11 – 15, 2017	September 18, 2017
IAEA	September 29, 2017	October 2 – 6, 2017	October 9, 2017
NMIJ	October 20, 2017	October, 2017	

* This schedule is the preliminary bilateral comparison for the stability test.

1. The time allowed for measurements for each participant is one week.
2. Allowance is made for a transportation time for the chambers of about two weeks.

3.7 Calibration results and measurement uncertainty

The pilot laboratory will provide the participants with MS-Excel sheets for reporting the participants' radiation qualities, primary standards, calibration results and its estimated uncertainty. The calibration coefficient uncertainty shall be evaluated according to the criteria given in the *"Guide to the expression of uncertainty in measurement"* [3]. The participants shall provide a detailed uncertainty budget (with $k = 1$).

3.8 Submission of calibration results

The participants shall submit to the pilot laboratory the MS-Excel file with the calibration results and the uncertainty estimation **within 6 weeks of calibration**. The pilot laboratory shall keep the results confidential until the Draft A is agreed by all the participants (see 3.10).

3.9 Analysis of results and linking

Two of the participating laboratories, the NMIJ/AIST and the NRC, took part in the international key comparison BIPM.RI(I)-K8 organized by the BIPM; the corresponding results will be used to link the APMP/TCRI regional comparison to the international comparison.

The comparison result of each participating NMI will be evaluated for each linking lab i (i = NMIJ/AIST, NRC) as

$$R_{\mathrm{NMI,LINK}_i} = \frac{N_{K,\mathrm{NMI}}}{N_{K,\mathrm{LINK}_i}} \qquad (3)$$

Where $N_{K,\mathrm{NMI}}$ and $N_{K,\mathrm{LINK}i}$ are the calibration coefficients obtained in the present comparison.

The comparison ratio with respect to the BIPM is evaluated for each linking laboratory i as

$$(R_{\mathrm{NMI,BIPM}})_i = R_{\mathrm{NMI,LINK}_i} . R_{\mathrm{LINK}_i,\mathrm{BIPM}} \qquad (4)$$

where $\mathrm{R}_{\mathrm{LINK_i,BIPM}}$ is the comparison result for laboratory i as published in the KCDB. As there are two linking laboratories, this will result in two values $(\mathrm{R}_{\mathrm{NMI,BIPM}})_i$ and the unweighted mean value will be taken:

$$\overline{R_{\mathrm{NMI,BIPM}}} = \frac{\sum_{i=1}^{2}(R_{\mathrm{NMI,BIPM}})_i}{2} \qquad (5)$$

The uncertainty $u_{R,\mathrm{NMI}}$ of this mean value will take correlation between the NMI and BIPM standards into account using equation (1b) of reference [4]

$$u_{R,\mathrm{NMI}}^2 = \left(u_{\mathrm{NMI}}^2 + u_{\mathrm{BIPM}}^2 - \sum_n f_n^2 \left(u_{\mathrm{NMI},n}^2 + u_{\mathrm{BIPM},n}^2 \right) \right) + u_{\mathrm{stab}}^2 + u_{\mathrm{LINK}}^2 \qquad (6)$$

where u_{stab} will be evaluated from the stability measurements at the NMIJ. The statistical uncertainty of the linking procedure, $u_{\mathrm{LINK}i}$, is evaluated for each linking laboratory i as described in [4] and the use of two linking laboratories should reduce the combined value (used in the above equation) according to

$$u_{\mathrm{LINK}} = \frac{\sum_{i=1}^{2} u_{\mathrm{LINK}_i}}{2\sqrt{2}} \qquad (7)$$

However, if the two values $(R_{\mathrm{NMI,BIPM}})_i$ do not agree at this level then u_{LINK} will be increased to reflect this discrepancy.

3.10 Comparison report

According to the guidelines "Measurement comparisons in the CIPM MRA" [5], if, on examination of the complete set of results, the pilot institute finds results that appear to be anomalous, the corresponding institutes will be invited to check their results to ensure that there are no arithmetic, typographical or transcription errors involved, but without being informed as to the magnitude or sign of the apparent anomaly. If no numerical error is found, the result stands.

The participants are not allowed to withdraw their results unless a reason not attributable to the performance of the laboratory can be assigned (for example, if an excessive drift or a malfunction is detected in the travelling standard). Individual values and uncertainties may be changed or removed or the complete comparison abandoned, only with the agreement of all participants and on the basis of a clear failure of the travelling standard or some other phenomenon that renders the comparison or part of it invalid.

At this stage, the pilot laboratory will prepare a Draft A report that includes the results transmitted by the participants, identified by name, for circulation to all participants for comments and discussion of the results.

As the results may be changed due the reasons explained above, Draft A (in all its versions) must be considered confidential and distributed among the participants only. As results may change, Draft A reports cannot be used as support for claiming CMCs.

Until all the participants have agreed on the report, it should be considered to be in Draft A stage, it being possible to have successive versions (Draft A1, A2,…etc).

Once the Draft is agreed by the participants, it will become the Draft B report, that will be submitted to the APMP/TCRI Chairman for approval and then to the CCRI Executive Secretary for circulation through the CCRI(I). After the agreement of the CCRI(I), the final report will be published as a Technical Supplement in *Metrologia*. In addition, the comparison report will be sent to the BIPM for inclusion in the key comparison database (KCDB).

3.11 Cost and notice

Participants shall pay any transportation costs to the next institute.

When participant receives and ships the transfer instruments, he should notify about the receipt and shipment to the NMIJ and the participants of the turn before and after him.

4. References

[1] BIPM.RI(I)-K8 Technical Protocol, Version 6.0, July 2014, http://kcdb.bipm.org/appendixB/appbresults/BIPM.RI(I)-K8/BIPM.RI(I)-K8_Technical_Protocol%20.pdf

[2] Chang L., Ho C., Lee J., Y Du and T Chen, 2008, A statistical approach to infer the minimum setup distance of a well chamber to the wall or the floor for ^{192}Ir HDR calibration Med. Phys. 35, 2214-2216.

[3] Evaluation of measurement data — Guide to the expression of uncertainty in measurement (GUM 1995 with minor corrections) JCGM 100: 2008.

[4] D. T. Burns and P. J. Allisy-Roberts, The evaluation of degree of equivalence in regional dosimetry comparisons, 2007, CCRI(I)/07-04.

[5] Measurement comparisons in the CIPM MRA, CIPM MRA-D-05, March 2016.

Appendix A

Addresses of the participants

Pilot laboratory

NMIJ

Research Institute for Measurement and Analytical Instrumentation
National Metrology Institute of Japan, NMIJ
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INER

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Telephone number: 886-3-4711400 Ext.7712
Fax number:886-3-4713489

KRISS

Korea Research Institute of Standards & Science (KRISS)
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Korea Research Institute of Standards & Science (KRISS)
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NMISA

Institute: National Metrology Institute of South Africa

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Institute: Malaysian Nuclear Agency

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NRC

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Telephone number: +1 613 993-2197 x260

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IAEA

Institute: IAEA/NA/NAHU/DMRP,

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Contact person: Ms Paula Toroi

E-mail address: P.Toroi@iaea.org

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PTKMR - BATAN

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Appendix B

Photographs of the chambers

Standard Imaging, HDR 1000 Plus and Holder