**2025-11-26**
**EURAMET Project 1782**

# Comparison in terms of reference air kerma rate for HDR Ir-192 using well-type chambers

**Identifier in the BIPM key comparison database (BIPM KCDB):**
**EURAMET.RI(I)-K8.x**

# Technical Protocol

*(approved by **EURAMET TC-IR** and **CCRI(I)**)*

Pilot laboratory: STUK (reporting) and SSM (measurements)


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**Contents**

# 1 Objective and participants

The national metrology laboratories for dosimetry quantities of the Netherlands (VSL, the National Metrology Institute of the Netherlands), Sweden (SSM, Swedish Radiation Safety Authority), Finland (STUK, Radiation and Nuclear Safety Authority), Norway (DSA, Norwegian Radiation and Nuclear Safety Authority), Italy (ENEA, Agenzia Nazionale per le nuove tecnologie), Serbia (VINS, Vinča Institute of Nuclear Sciences - National Institute of the Republic of Serbia, University of Belgrade), Greece (EEAE, Greek Atomic Energy Commission), Croatia (RBI, Ruđer Bošković Institute) and the International Atomic Energy Agency (IAEA) have agreed to perform a comparison in terms of reference air kerma rate (RAKR) for HDR $^{192}$Ir using well-type chambers. All participating laboratories, apart from VSL, are secondary standards dosimetry laboratories (SSDLs) for the respective quantity. IAEA is the only SSDL to maintain its own $^{192}$Ir source, while the other SSDLs perform calibrations at hospitals.

In the project two well-type transfer chambers will be circulated among participants, and each laboratory will report calibration coefficients and their expanded uncertainties for these chambers in terms of reference air kerma rate. VSL as a primary standards dosimetry laboratory will provide a link to the BIPM.RI(I)-K8 comparison throughout this comparison.

This technical protocol prepared by the laboratories specifies the procedure to be followed in this dosimetry comparison. The technical protocol is prepared according to the BIPM technical protocol for the ongoing BIPM key comparison BIPM.RI(I)-K8. The purpose of a comparison is to compare the calibration capabilities of the participating laboratories, not to require each participant to adopt precisely the same conditions of measurement. The protocol, therefore, specifies the procedures necessary for the comparison, e.g. reference conditions, but not the procedures used in the calibration of the laboratories being compared.

## 1.1 Objective of the comparison

The objective of the comparison is to support the ionising radiation CMCs of SSM, IAEA, EEAE, RBI, VINS, ENEA, STUK, and DSA, in the dosimetry branch for the quantity reference air kerma rate (RAKR) for HDR $^{192}$Ir.

## 1.2 Participants

Table 1 lists the participants. In Appendix I, the complete contact details for the participants are presented. Table 2 presents the traceability of participating laboratories in terms of RAKR for $^{192}$Ir.

Table 1. Participants of the project in the order of measurements.

| Institute | Country | Contact person | e-mail |
|---|---|---|---|
| SSM (pilot, measurements) | Sweden | Linda Persson | linda.persson@ssm.se |
| VSL (reference value) | Netherlands | Grazia Brazzorotto<br>Jacco de Pooter | gbrazzorotto@vsl.nl<br>jdpooter@vsl.nl |

| | | | |
|---|---|---|---|
| IAEA | International, Austria | Zakithi Msimang | z.msimang@iaea.org |
| EEAE | Greece | Argiro Boziari | argiro.boziari@eeae.gr |
| RBI | Croatia | Luka Bakrac | lbakrac@irb.hr |
| VINS | Serbia | Milos Zivanovic | milosz@vin.bg.ac.rs |
| ENEA | Italy | Alessia Ciccotelli | alessia.ciccotelli@enea.it |
| STUK (pilot, reporting) | Finland | Reetta Nylund | reetta.nylund@stuk.fi |
| DSA | Norway | Per Otto Hetland | per.otto.hetland@dsa.no |

Table 2. Traceability of calibrations at the participating laboratories in terms of reference air kerma rate for HDR $^{192}$Ir.

| Institute | $^{192}$Ir Traceability | Type of standard |
|---|---|---|
| SSM | PTB | Secondary |
| VSL | VSL | Primary |
| IAEA | PTB | Secondary |
| EEAE | LNE-LNHB | Secondary |
| RBI | PTB via IAEA | Secondary |
| VINS | PTB via IAEA | Secondary |
| ENEA | VSL | Secondary |
| STUK | NPL | Secondary |
| DSA | PTB via IAEA | Secondary |

## 2 Transfer instruments

Two well-type ionization chambers of the same type and manufacturer will be used as transfer instruments for this comparison. Two chambers will be used to minimize the risk of potential transfer instrument breakage during the comparison. If a chamber suffers a failure during the comparison, the comparison will be continued with the other chamber, listed in this protocol. If there are results for a particular chamber from at least a half of the participating laboratories, results will be reported in the final publication. The chambers are owned by different laboratories participating in the comparison and these laboratories have stability data for these chambers available, which can be used if needed to evaluate the chamber stability during the comparison. No electrometer is circulated, and laboratories shall use their own electrometers and cables for performing the measurements during the comparison and ensure traceability for their current measurement and high-voltage setting applied to the ion chamber. The details of the measurement equipment (e.g. afterloader used) shall be specified when reporting results.

The technical details of the chambers are listed in table 3.

Table 3. Technical data of the transfer chambers (chamber characteristics according to IAEA TRS492 and manufacturer's information).

| Chamber type (owner of chamber) | Standard Imaging HDR 1000 Plus (SSM) | Standard Imaging HDR 1000 Plus (IAEA) |
|---|---|---|
| Serial number | A062722 | #A953382 |
| Geometry | well-type | well-type |
| Active volume | 245 $cm^3$ | 245 $cm^3$ |
| Height | 15.6 cm | 15.6 cm |
| Diameter | 10.2 cm | 10.2 cm |
| Insert height | 12.1 cm | 12.1 cm |
| Insert diameter | 3.5 cm | 3.5 cm |
| Accompanying insert | Standard Imaging HDR Ir source holder 70010, labelled Br2 RMP06 | Standard Imaging HDR Ir source holder 70010 |
| Polarising voltage of a chamber | +300 V on collector (central) electrode, 0 V on chamber wall (collecting negative charge) (if +300 V on collector is not available: -300 V on chamber wall, 0 V on collector electrode) | +300 V on collector (central) electrode, 0 V on chamber wall (collecting negative charge) (if +300 V on collector is not available: -300 V on chamber wall, 0 V on collector electrode) |
| Connector type | BNC (BNT 2-lug) | BNC (BNT 2-lug) |
| Nominal source holder reference points | Black dot on the insert and dot on the top of the chamber housing | Black dot on the insert and dot on the top of the chamber housing |
| Sweet spot | Shall be determined separately by each participant (nominal maximum response at about 50 mm from the bottom of the chamber insert) | Shall be determined separately by each participant (nominal maximum response at about 50 mm from the bottom of the chamber insert) |
| Other remarks | Figure A1 | Figure A2 |

## 3 Measurement procedure

The dosimetry laboratories are expected to ensure that their reference standard is in perfect working order prior to the comparison. When the participant receives the transfer chambers, they shall perform a visual check for any damage and verify correct functioning prior to any additional measurements. If it seems that the chambers are broken, the participant should contact the piloting laboratories STUK and SSM to discuss further actions.

Each participant will proceed following their own calibration procedure(s) according to their quality management system to determine the calibration coefficients of the transfer chambers in terms of reference air kerma rate. Whenever possible, all calibration results shall be given corrected to Elekta Flexisource HDR Ir-192 and plastic catheter, which is the reference for this comparison. This can be performed by applying the source model correction factor e.g. according to the method in IAEA TRS-492 and the data in TRS-492 Table 8, and the participant needs to report how the conversion is performed. An uncorrected value can be given if the conversion to Flexisource is not possible. Then the participant is responsible for considering the effect of the estimated correction in the uncertainty budget. Furthermore, each laboratory may add any other correction factors needed for calibrations and these correction factors shall be reported when reporting results.

### 3.1 Radiation qualities and quantities

The radiation quality used in the comparison is $^{192}$Ir. The quantity used for the comparison is reference air kerma rate defined according to ICRU85a. Primary standards used in the comparison and as source of traceability (Table 2) should have the ICRU90 recommendations regarding the reference data for primary standards implemented.

### 3.2 Reference conditions

The calibration coefficients for the transfer chambers should be given in terms of reference air kerma rate in units of Gy/C, determined at the point of maximum chamber response (sweet spot) and corrected to standard conditions of air temperature and pressure; $T_0$ = 293.15 K and $P_0$ = 101.325 kPa. Corrections for relative humidity (RH = 50%) will not be applied for the measurements performed between 20% and 80% RH. Each laboratory will use their own equipment to measure environmental conditions and ensure traceability for those measurements.

### 3.3 $^{192}$Ir source

Each participant may choose their usual source construction/type and activity. As the well chamber responses are dependent on the $^{192}$Ir source design, the source reference code, manufacturer and activity should be reported. Furthermore, the results should be corrected into same geometry as the reference value for this comparison using the source model correction factor.

### 3.4 Reference value

VSL as linking laboratory to BIPM.RI(I)-K8 will provide the link to the BIPM.RI(I).K8 KCRV (Key Comparison Reference Value) for this comparison. VSL will proceed according to the same procedures as for the latest comparisons.

VSL will perform reference measurements using an Elekta Flexitron afterloader and plastic catheter for Standard Imaging chambers.

The reference values will be calculated separately for each chamber and the values reported by SSDLs will be compared to the reference value by calculating a ratio between calibration coefficients of the SSDL and linking laboratory (VSL), e.g. $K_{RAKR,SSDL}/K_{RAKR,LINK}$.

### 3.5 Determination of the calibration coefficient

Each laboratory details their own procedure or refers to international practices/ guidance followed when performing the calibration. Several of SSDLs will perform measurements at hospitals and will follow their own procedures for this.

Typically, the laboratory measures the position of maximum chamber response (sweet spot) by stepping a brachytherapy source through the well chamber. This position shall be reported in the comparison report, for instance as the distance from the tip of the (plastic) catheter (which is pushed to the bottom of the borehole in the chamber holder) and the centre of the Ir-192 source at the sweet spot, including the length of the catheter.

Typically, the SSDL establishes a reference air kerma rate of an $^{192}$Ir HDR source in accordance with their own procedure following an equation such as:

$$\dot{K}_{RAKR} = N_{\dot{K}_{RAKR},SSDL} I_{SSDL} \ (1)$$

where $N_{\text{KRAKR,SSDL}}$ is the calibration coefficient for reference air kerma rate determined by a primary standards dosimetry laboratory (PSDL) for a specific HDR $^{192}$Ir source model, and where $I_{\text{SSDL}}$ is the ionisation current measured by the SSDL with an electrometer system with traceability to electrical standards. In accordance with TRS-492, $I_{\text{SSDL}}$ is corrected to reference conditions of air temperature and pressure (T=20 °C and P=101.325 kPa) ($k_{Tp}$), and if needed for relative humidity, chosen for the comparison. Furthermore, the relevant source model correction factor, $k_{sm,sm_0}$ , should be applied to $N_{\text{K\_RAKR,PSDL}}$ if the type of source used at the SSDL is different to the source used for the calibration of the well-type chamber at the PSDL. For the corrections to $I_{\text{SSDL}}$, a laboratory shall proceed according to their own procedure and may include e.g. the electrometer correction factor, correction for leakage, correction for distance, correction for volume, correction for ion recombination etc. All corrections used shall be reported in addition to the final results and they all contribute to the uncertainty budget.

Each SSDL calibrates the transfer chamber for reference conditions using their usual calibration procedure to derive the calibration coefficient for the transfer chamber, $N_{\text{RAKR,tr}}$, which is defined as:

$$N_{RARK,tr} = \frac{\dot{K}_{RAKR}}{I_{tr}} \qquad (2)$$

where $\dot{K}_{RAKR}$ is the reference air kerma rate from equation (1), and where $I_{\mathrm{tr}}$ is the signal from the transfer chamber measured by the SSDL at the specific reference polarity stated in table 3 using their own electrometer systems with traceability to electrical standards. Like $I_{\mathrm{SSDL}}$, $I_{\mathrm{tr}}$ is corrected to standard conditions of air temperature and pressure, and if needed for relative humidity, chosen for the comparison. Similar corrections as for $I_{\mathrm{SSDL}}$ should be applied to $I_{\mathrm{tr}}$.

VSL will determine calibration coefficients in the same way as the SSDLs, except that realization of the quantity RAKR is performed at VSL using their primary method to realize reference air kerma, as described in the respective comparison reports (Kessler C. *et al*., 2024 and van Dijk *et al*., 2004).

### 3.6 Uncertainty budgets

In addition to calibration coefficients each participant shall provide a detailed measurement uncertainty budget considering all influence parameter and correction factors for each calibration coefficient. Each participant shall describe the main components of the uncertainty including correction factors in the budget in the level of one standard uncertainty and provide the final expanded combined uncertainty, $k$=2. The detailed uncertainty budget shall be provided in accordance with the Guide to the Expression of Uncertainties in measurements (JCGM, 2008) with corresponding confidence level. Components of the uncertainty budget shall be provided as relative values [%]. The Excel report sheet includes an example form for the uncertainty budget, into which each laboratory is recommended to add components according to their procedures.

### 3.7 Reporting the results

The pilot laboratory (STUK) will send their results to the CCRI Executive Secretary Vincent Gressier (vincent.gressier@bipm.org) within 6 weeks of completing their measurements. Other participants will send their results (calibration coefficients and uncertainty budgets) with information of the measuring set-up to STUK (reetta.nylund@stuk.fi) after STUK has sent their measurements to the CCRI Executive Secretary. As the STUK will be one of the last participants performing the measurements, all other participants will keep their results confidential until then. SSM will deliver data for chamber stability within 2 weeks of completing their stability measurements, after which STUK will begin data analysis. If a participant has not sent their results (calibration coefficient and uncertainty budgets) by the due date, the laboratory will be excluded from the comparison.

A common Excel template for reporting the results will be provided to each participant in addition to this technical protocol.

Before the draft A is delivered to participants, the pilot laboratory (STUK) will confirm with all participants that they will participate using the given results. If there is not enough information available, e.g., uncertainty budgets don’t include all needed components to estimate/calculate degrees of equivalence for the comparison, the pilot laboratory (STUK) reserves the right to contact the participant to obtain the details. In this case a participant is expected to answer within two weeks to the pilot laboratory to keep the comparison on track.

### 3.8 Evaluation of the results

After the reporting pilot laboratory (STUK) has received all results, the results of the SSDLs will be evaluated in comparison with VSL's results, as VSL provides a link to the KCRV of this comparison. The results will be analysed for each transfer chamber. Degrees of equivalence will be calculated in terms of comparison results (calibration coefficients and uncertainties) according to CCRI(I)/17-09 instructions. In general, the degree of equivalence of each SSDL, with respect to the KCRV, is evaluated as follows separately for each transfer chamber:

$$R_{SSDL} = \frac{N_{RAKR,SSDL}}{N_{RAKR,VSL}} R_{VSL,BIPM} \quad (3)$$

in which $R_{VSL,BIPM}$ represents the results of VSL in the BIPM.RI(I)-K8 key comparison (Kessler C et al, 2024).

The variance of $R_{SSDL}$ is:

$$u^2_{R,SSDL} = (u^2_{SSDL} + u^2_{BIPM} - \sum_j f_j^2 (u^2_{SSDL,j} + u^2_{BIPM,j})) + u^2_{tr} + u^2_{LINK} \quad (4)$$

in which $f_j$ are weighting factors related to correlating components, which will be evaluated during the analysis.

In equation (4) $u_{tr}$ combines the stability of the transfer chambers over the period of the comparison and the variation in the ratios for a specific chamber. $u_{tr}$ will be calculated based on standard uncertainties of $R_{SSDL}$ (from equation (5)) for each laboratory according to CCRI(I)/17-09. Additionally, the pilot laboratory (SSM) will perform several measurements for each transfer chamber and $u_{tr}$ may also be calculated and adjusted based on these (e.g. if SSM's repeatability data is significantly higher than $u_{tr}$, i.e. more than two standard deviations). If needed, stability data from chamber owners may be used to evaluate chamber stability. If $u_{tr}$ is significantly higher (more than two standard deviations) for a specific chamber, that chamber will be excluded from the comparison.

In equation (4) $u_{VSL}$ represents the uncertainty of non-statistical components, which are not cancelling out via the linking mechanism. To ease estimation of these, VSL's measurement conditions in this comparison are as close as possible to those used in the VSL-BIPM comparison. However, a possible uncertainty due to intra-type variation of sources might be added into the linking mechanism.

For the case of the 2 transfer chambers which will be circulated in this comparison, equation (3) becomes:

$$R_{SSDL} = \left(\frac{N_{RAKR,VSL}}{N_{RAKR,BIPM}}\right) \frac{1}{2} \sum_{j=1}^{2} \frac{N_{RAKR,SSDL,j}}{N_{RAKR,VSL,j}} \quad (5)$$

Equation (5) will eventually be used for the analysis, if both transfer chambers are used for the analysis of results.

The degree of equivalence for the SSDL is:

$$D_{SSDL} = R_{SSDL} - 1 \qquad (6)$$

and its expanded uncertainty is $U_{\mathrm{SSDL}}=2u_{\mathrm{R,SSDL}}$.

Further details for data analysis may be discussed among the participants on the basis of the Draft A report.

In the reporting of the results, document "CIPM MRA-G-11: Measurement comparisons in the CIPM MRA, Guidelines for organizing, participating and reporting" will be followed.

# 4 Course of comparison

## 4.1 Transport and time schedule

The laboratory should make all the arrangements for safe transport of the transfer standards once measurements have been completed. Each participating institute is responsible for its own costs regarding the measurements and transportation of the transfer instruments to the next institute. The standards won't be insured by the pilot, and each participant is responsible for the good care of the chambers in their facilities and good packing of the chambers for the subsequent shipment. Each participant is responsible for the chambers within their country and onward shipment until the receiving laboratory has received the equipment. Shipment shall be made using a courier. It is recommended to take photographs of the chambers before the shipment.

The laboratories outside of the EU (Serbia, Norway) will perform their measurements in the neighbouring EU-country as onsite calibration (as they would perform calibrations at a hospital in their home countries) and thus, the transfer chambers won't be shipped outside of the EU. Laboratories outside of the EU are responsible for their own travel to neighbouring countries as well as transport of their equipment.

IAEA will ship to SSM at IAEA cost at the beginning of the comparison for stability measurements and SSM will provide shipping of the chambers back to IAEA at the end of the comparison.

The transfer standards are packed in a Pelican protection box together with a complete description of the devices (i.e. technical protocol) including information about the manufacturer, type, serial number, size, weight and technical data needed for their operation. The package is 55 cm x 26 cm x 48 cm and it weighs 15.7 kg.

Table 4 summarises the proposed schedule of the comparison measurements and table 5 summarises the course of the comparison events. Comparison measurements will begin before the final approval of the technical protocol due to the availability of $^{192}$Ir.

Table 4. Prosed schedule for the comparison measurements. The measurements have been started before the full acceptance of the technical protocol.

| Institute | Measuring period | Date of chamber leaving to next participant |
|---|---|---|
| SSM, stability check | October 2025 | October 31st, 2025 |
| VSL | November 2025 | Nov 30th, 2025 |
| IAEA | December 2025 | Dec 31st, 2025 |
| EEAE | January 2026 | Jan 31st, 2026 |
| RBI | February 2026 | Feb 28th, 2026 |
| VINS | February 2026 | |
| ENEA | March 2026 | Mar 30th, 2026 |
| STUK | April 2026 | Apr 30th, 2026 |
| DSA | May 2026 | |
| SSM, measurements and stability check | May-June 2026 | June 15th, 2026 |

Table 5. Proposed comparison events.

| Event | Due date |
|---|---|
| IAEA ships a transfer standard to SSM | October 3rd, 2025 |
| SSM ships both transfer standards to VSL | October 31st, 2025 |
| Comparison measurements (see table 4) | November 2025 |
| STUK sends results to BIPM<br><br>Participants shall not send their results before to STUK! | May 31st, 2026 |
| Final due date for results to STUK | June 30th, 2026 |
| Chamber stability measurement reported (from SSM to STUK) | June 30th, 2026 |
| Draft A delivered to participants | September 15th, 2026 |
| Comments by the participants on draft A | October 10th, 2026 |

| | |
|---|---|
| Draft B available | December 1st, 2026 |
| Final report available | Depending upon comments by evaluators |

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## Appendix I: Complete addresses of the participants used for shipments

**SSM / Sweden**
Swedish Radiation Safety Authority (SSM)
Riksmätplatsen
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**RBI / Croatia**
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**ENEA / Italy**
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**Appendix II. Pictures of transfer chambers.**

Standard Imaging HDR 1000 Plus A062722

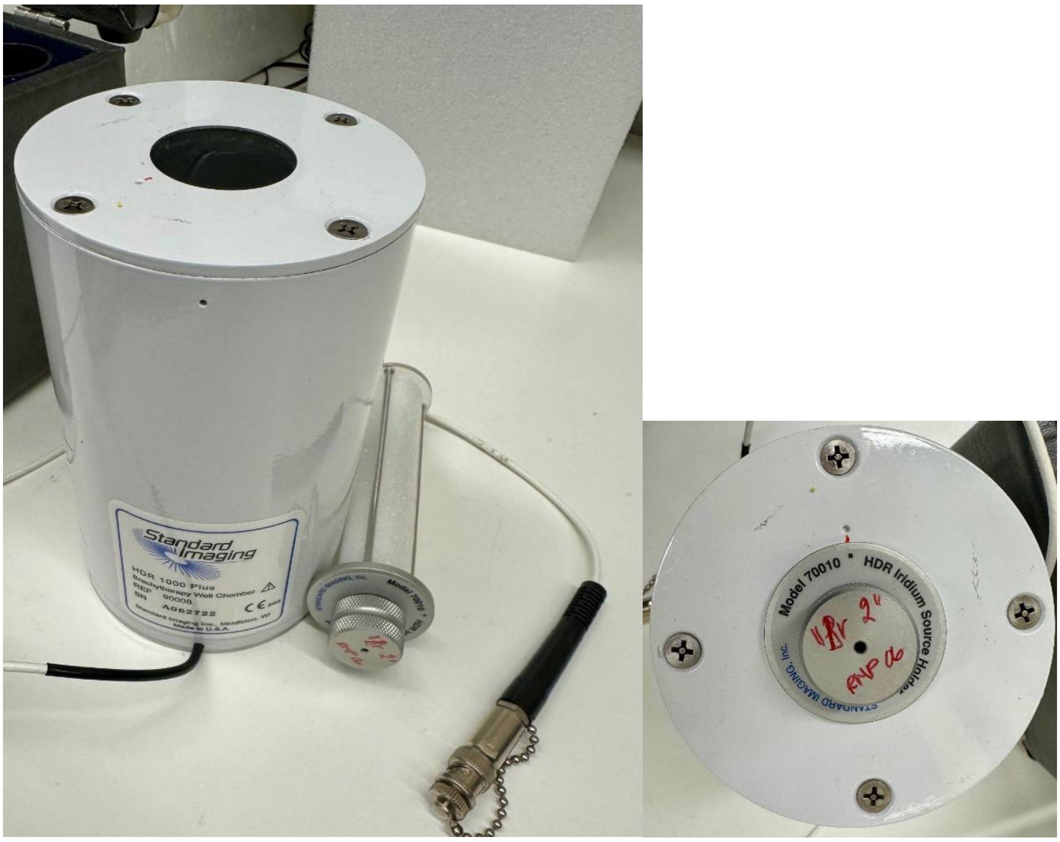


Figure A1. Standard Imaging HDR 1000 Plus, s/n A062722. The picture on the right shows the correct alignment of the Standard Imaging HDR Iridium Source Holder, model 70010, labelled Br2 RMP06.

Standard Imaging HDR 1000 Plus A953382


Figure A2. Standard Imaging HDR 1000 Plus, s/n A953382. The other transfer chamber is exactly similar as another chamber (the source holder in figure is not correct holder).