EURAMET Project 1541

Comparisons of air kerma and absorbed dose to water standards in ^{60}Co radiation beam for radiation therapy

Identifier in the BIPM key comparison database (BIPM KCDB):

EURAMET.RI(I)-K1.3
EURAMET.RI(I)-K4.3

Technical Protocol

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

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

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1 Object and participants

The national metrology laboratories for dosimetry quantities of Netherlands (VSL, the Dutch National Metrology Institute), Sweden (SSM, Swedish Radiation Safety Authority), Norway (DSA, Norwegian Radiation and Nuclear Safety Authority), Finland (STUK, Radiation and Nuclear Safety Authority), Denmark (DTU, Technical University of Denmark), Spain (CIEMAT, the Spanish National Metrology Institute for Ionising Radiation), and the International Atomic Energy association (IAEA) have agreed to perform a comparison in terms of air kerma and absorbed dose to water in ^{60}Co radiation therapy beams. All participant laboratories, with the exception of VSL, are secondary standard laboratories (SSDLs).

In the project three transfers chambers will be circulated among participants and each laboratory will report calibration coefficients and their expanded uncertainties for those chambers in terms of air kerma and absorbed dose to water. VSL as a primary dosimetry laboratory will provide a link to the BIPM.RI(I)-K1 and BIPM.RI(I)-K4 comparisons throughout this comparison, since other participating laboratories are secondary standard dosimetry laboratories.

This technical protocol prepared by the laboratories specifies the procedure to be followed in this particular dosimetry comparison. The technical protocol is prepared according to the BIPM technical protocols for BIPM ongoing key comparisons BIPM.RI(I)-K1 and BIPM.RI(I)-K4. The purpose of a comparison is to compare the calibration results 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, DSA, DTU, STUK, CIEMAT, and IAEA in the dosimetry branch for the quantities of air kerma/rate and absorbed dose to water/rate from a ^{60}Co source at radiation therapy levels.

Additionally, STUK will move into new facilities during the comparison period and will perform the measurements twice, in the current and in the future facilities to support its ability of maintain CMCs during the delocalization. Similarly, VSL will replace their ^{60}Co-facility and will perform two measurement sets. The first measurement set will be considered as a comparison reference value and the second set of measurements will support maintaining of VSL's CMCs after replacement of ^{60}Co-facility.

1.2 Participants

Table 1 lists the participants. In the Appendix I, the complete contact details for the participants are presented. Table 2 presents the traceability of participating laboratories in terms of K_{air} and D_w in ^{60}Co radiation therapy beam.

Table 1. Participants of the project.

Institute	Country	Contact person	e-mail
VSL	Netherlands	Leon de Prez	ldprez@vsl.nl
SSM (pilot, measurements)	Sweden	Linda Persson	linda.persson@ssm.se
DSA	Norway	Per Otto Hetland	per.otto.hetland@dsa.no
STUK (pilot, reporting)	Finland	Reetta Nylund	reetta.nylund@stuk.fi
DTU	Denmark	Claus E. Andersen	clan@dtu.dk
CIEMAT	Spain	Cristina García Mulas	cristina.garcia@ciemat.es
IAEA	International, Austria	Zakithi Msimang	z.msimang@iaea.org

Table 2. Traceability of calibrations at the participating laboratories in terms of K_{air} and $D_{\mathbf{w}}$ in ^{60}Co radiation therapy beam.

Institute	^{60}Co Traceability	Type of standard
VSL	VSL	Primary
SSM	BIPM	Secondary
DSA	BIPM	Secondary
STUK	BIPM	Secondary
DTU	PTB	Secondary
CIEMAT	BIPM	Secondary
IAEA	BIPM	Secondary

2 Transfer instruments

Three reference ionisation chambers will be used as transfer instruments for this comparison. Three 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 chambers, which are listed in this protocol. If there are results from a half of the participating laboratories, results will be reported in the final publication. The chambers are a property of three different laboratories participating in the comparison and these laboratories have stability data for these chambers available, which can be used if needed to evaluate chamber stability during the comparison. These chambers have not been calibrated outside the laboratory before this 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. technical mode) shall be specified when reporting results.

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

Table 3. Technical data of the transfer chambers (chamber characteristics according to IAEA TRS398).

Chamber type (owner of chamber)	**IBA FC65-G (SSM)**	**IBA FC65-G (STUK)**	**NE2571 (DTU)**
Serial number	4442	3578	3714
Geometry	thimble	thimble	thimble
Wall material	graphite	graphite	graphite
Wall thickness [g cm^{-2}]	0,073	0,073	0,065
External diameter / mm	8,6 (stem diameter)	8,6 (stem diameter)	8,62 (stem outside diameter)
Cavity length/ mm	23,1	23,1	24,0
Cavity diameter or radius	Cavity radius 3,1 mm	Cavity radius 3,1 mm	Cavity radius 3.2 mm (thimble outside diameter 6,99)
Nominal volume / cm^3	0,65	0,65	0,69
Build-up cap for air kerma measurements	Chamber's own build-up cap (3,9 mm; 0,560 g/cm^2)	Chamber's own build-up cap (3,9 mm; 0,560 g/cm^2)	Chamber's own build-up cap (0,551 g/cm^2)
Reference point for the absorbed dose measurements in water	On the central axis, 13 mm from the distal end of the chamber tip	On the central axis, 13 mm from the distal end of the chamber tip	On the central axis, 13 mm from the distal end of the chamber tip
Reference point for the air kerma measurements using a build-up cap	On the central axis, 13 mm from the distal end of the chamber tip (without build-up cap)	On the central axis, 13 mm from the distal end of the chamber tip (without build-up cap)	On the central axis, 13 mm from the distal end of the chamber tip (without build-up cap)

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)	+250 V on collector (central) electrode, 0V on chamber wall (collecting negative charge) (if +250 V on collector is not available: -250 V on chamber wall, 0 V on collector electrode)
Connector type	TNC triaxial	TNC triaxial	TNC triaxial
Other remarks	Waterproof, but a maximum of 6 hrs in the water and allow at least 24 hrs for drying before build-up cap is put back on	Waterproof, but a maximum of 6 hrs in the water and allow at least 24 hrs for drying before build-up cap is put back on	NOT waterproof (laboratory's own sleeve is to be used for comparison) details of the sleeve to be described in the results (material, thickness)

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 air kerma and absorbed dose to water. Furthermore, each laboratory may add needed correction factors for calibrations and these correction factors shall be reported when reporting results. Each participant shall report the orientation of the source relative to the water phantom for the absorbed dose to water measurements.

3.1 Radiation qualities and quantities

The radiation quality used in the comparison is ^{60}Co. The quantities used for the comparison are air kerma and absorbed dose to water. Radiation quantities are according to ICRU90 and each participant is expected to have implemented any necessary changes before participating in the comparison.

3.2 Reference conditions

The reference source to chamber distance for a ^{60}Co beam is 100 cm along the central beam axis for both measured quantities and the reference field size is 10 cm x 10 cm for both quantities at this measurement distance. The reference points for chambers are described in table 3. For the chamber setup, the marking on the stem shall be oriented facing the radiation source. For absorbed dose to water the chambers are to be calibrated in such a manner that the reference point of the chamber is to be placed approximately at the depth of 5 g/cm^2 in a water phantom, using a waterproof sleeve when appropriate. For air kerma the chambers are placed free in the air.

The calibration coefficients for the transfer chambers should be given in terms of air kerma and absorbed dose to water per charge in units of Gy/C and corrected to standard conditions of air temperature and pressure; T = 293,15 K and P = 101,325 kPa. The reference conditions for relative humidity (RH = 50%) will not be corrected 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.

The reference conditions are according to rapport BIPM-2018/06.

3.3 Reference value

VSL as linking laboratory to BIPM.RI(I)-K1 and BIPM.RI(I)-K4 comparisons will provide reference value for this comparison. VSL will proceed according to the same procedures as for the latest comparisons. All other results will be compared to this value. None of the participating laboratories are traceable to VSL for the comparison quantities. As VSL will perform two measurement sets, the first measurement set, which is performed in the beginning of the comparison, will act as a reference value for the comparison. Additionally, VSL will perform another measurement set in the later phase of the comparison, which will be reported but not used for calculating reference values for this comparison. This second measurement will be performed after the change of Co-60 facility at VSL and will serve for internal linking for VSL.

The Reference values will be calculated separately for each chamber and the values reported by by SSDLs will be compared to the reference value by calculating a ratio between calibration coefficients of VSL and SSDL, e.g. $N_{D,w,VSL}/N_{D,W,SSDL}$.

3.4 Determination of the calibration coefficient

Each laboratory details their own procedure or refers to international practices/ guidance followed when performing the calibration. Typically for absorbed dose to water, SSDL establishes a reference rate for absorbed dose to water $\dot{D}_\mathrm{w}$ at their facilities in accordance with their own procedure following an equation such as:

$$\dot{D}_w = N_{\mathrm{D,w,PSDL}} I_{\mathrm{SSDL}} \qquad (1)$$

where $N_{\mathrm{D,w,PSDL}}$ is the calibration coefficient used by the given SSDL in order to reach traceability to a primary standard laboratory for absorbed dose to water measurements in ^{60}Co beams, and where I_{SSDL} is the ionisation current measured by the SSDL with an electrometer system with traceability to electrical standards. In accordance with TRS-398, I_{SSDL} is corrected to standard conditions of air temperature and pressure (T=20 °C and P=101.325 kPa), and if needed for relative humidity, chosen for the comparison. For the other corrections to I_{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 etc. All corrections used shall be reported in addition to the final results.

Each SSDL positions a transfer chamber at the reference set-up such that the calibration coefficient for the transfer chamber $N_{D,w}$ is computed as:

$$N_{\mathrm{D,w}} = \frac{\dot{D}_{\mathrm{w}}}{I_{\mathrm{M}}} \qquad (2)$$

where $\dot{D}_w$ is the reference absorbed dose to water rate from equation (1), and where I_M 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_{SSDL}, I_M 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_{SSDL} may be applied to I_M.

A similar procedure to achieve calibration coefficients N_K for the transfer chambers in terms of air kerma $\dot{K}_{air}$ is applied.

VSL will determine calibration coefficients in the same way as the SSDLs, except that realization of the quantity is performed at VSL using their air kerma and absorbed dose to water primary standards, respectively a cavity ion chamber and a water calorimeter, as described in the respective comparison reports (Kessler C. et al., 2017).

As a supplementary investigation, DTU will measure both initial and volume recombination using the Niatel method (Andreo et al., 2017) for all transfer chambers. The measurements of volume recombination provide a direct estimate of changes in recombination associated with differences in dose rates during the comparison as participants have varying dose rates for their ^{60}Co sources. If sufficient, this information will be published as a supplementary information, but other participants data will not be corrected with these factors.

3.5 Uncertainty budgets

In addition to calibration coefficients each participant shall provide a detailed measurement uncertainty budget for each calibration quantity. Each participant shall describe the main components of the uncertainty 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 and information on the number of degrees of freedom. Components of the uncertainty budget shall be provided as relative values [%]. It is expected that in these measurements, participants achieve the best uncertainty that is regularly available. The report Excel sheet includes an example form for the uncertainty budget, into which each laboratory is recommended to add components according to their procedures.

3.6 Reporting the results

The measuring pilot laboratory (SSM) 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) to SSM (linda.persson@ssm.se) within 6 weeks of completing their measurements. VSL shall keep confidential their results from the first measurement set until SSM has sent their measurement results to the CCRI Secretary and shall send their results to SSM at the beginning of February. After STUK has performed the second measurement set, SMM will share the results with STUK for data-analysis. The last measurement set by SSM is used only to check stability of the transfer chambers and it will not be published as a separate result. For STUK and VSL two measurement sets will be reported. For STUK's future services the second measurement set is more representative. As an additional stability data set for the chambers, the chamber owners' follow-up data for each of the chambers might be used. SSM will deliver data for chamber stability within 2 weeks of completing their second measurement set, after which STUK will begin data analysis. All results shall be received by STUK by the middle of November 2022. 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 the technical protocol.

Before the draft A is delivered to participants, the pilot laboratory (STUK) will confirm from 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 particular details. In this case a participant is expected to answer quickly (i.e. within two weeks) to the pilot laboratory in order to keep the comparison on track.

3.7 Evaluation the results

After the reporting pilot laboratory (STUK) has received all results, i.e., in middle of November 2022, the results of the SSDLs will be evaluated in comparison to VSL's results from the first measurement set, as VSL provides a reference value for this comparison. The results will be analysed for single chambers. Degrees of equivalence will be calculated in terms of comparison results (calibration coefficients and uncertainties) according to CCRI(I)/17-09 instructions. In general, and for the specific case of the quantity absorbed dose to water, the degree of equivalence of each SSDL, with respect to the key comparison reference value, is evaluated as follows separately for each transfer chamber:

$$R_{SSDL} = \frac{N_{D,w,SSDL}}{N_{D,w,VSL}} R_{VSL,BIPM} \qquad (3)$$

in which $R_{VSL,BIPM}$ represents the results of VSL in BIPM comparison (Kessler C et al, 2017).

A variance of R_{SSDL} is:

$$u_{R,SSDL}^2 = (u_{SSDL}^2 + u_{BIPM}^2 - \sum_j f_j^2 (u_{SSDL,j}^2 + u_{BIPM,j}^2)) + u_{tr}^2 + u_{VSL}^2 \qquad (4)$$

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

In the equation (4) u_{tr} combines the stability of the transfer chambers over the period of the comparison and the variation in the ratios for specific chamber. u_{tr} will be calculated based on standard uncertainties 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 repeatability data is significantly higher than u_{tr}, 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 linking mechanism. To ease estimation of these VSL's measurements conditions in this comparison are as close as possible to those used in the VSL-BIPM comparison.

For the case of the 3 transfer chambers which will be circulated in this comparison, equation (3) for the quantity absorbed dose to water becomes:

$$R_{SSDL} = \left(\frac{D_{w,VSL}}{D_{w,BIPM}}\right) \frac{1}{3} \sum_{j=1}^{3} \frac{N_{Dw,SSDL,j}}{N_{Dw,VSL,j}} \; (5)$$

The degree of equivalence for 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 instrument 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. Shipping outside/back to EU, i.e., to Norway and back, is done from SSM, and SSM and DSA will agree the share of the costs. The owners providing the transfer chambers will cover the shipping cost to VSL at the beginning of the comparison and SSM will cover the cost of shipping the equipment back at the end. Shipment shall be made using a courier. It is recommended to take photographs of the chambers before the shipment.

The transfer standards are packed in a Pelican protection box together with a complete information 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 information also includes weight and size of the whole package as well as value of the equipment for customs purposes.

The measurements will start in October 2021 at VSL and the last measurements are scheduled to be performed in October 2022 at SSM. The chambers are calibrated twice at STUK (in two locations, separate timing) and VSL (in two facilities, separate timing), and once in the other participating laboratories DSA, DTU, CIEMAT, and IAEA. Table 4 summarises the proposed schedule of the comparison measurements and table 5 summarises the course of the comparison events.

Table 4. Prosed schedule for the comparison measurements.

Institute	Measuring period	Date of chamber leaving to next participant
VSL	October 2021	November 5th, 2021 (1
SSM	November-December 2021	Dec 20th, 2021
DSA	January 2022	Feb 4th, 2022
STUK	February -March 2022	March 18th, 2022
DTU	March -April 2022	May 13th, 2022
CIEMAT	May-June 2022	June 17th, 2022
IAEA	June-July 2022	August 1st, 2022
STUK	August 2022	September 1st, 2022
VSL	September 2022	October 1st, 2022
SSM	October 2022	November 1st, 2022 transfer chambers returned

(1 The measurements were initiated before the protocol was fully reviewed.

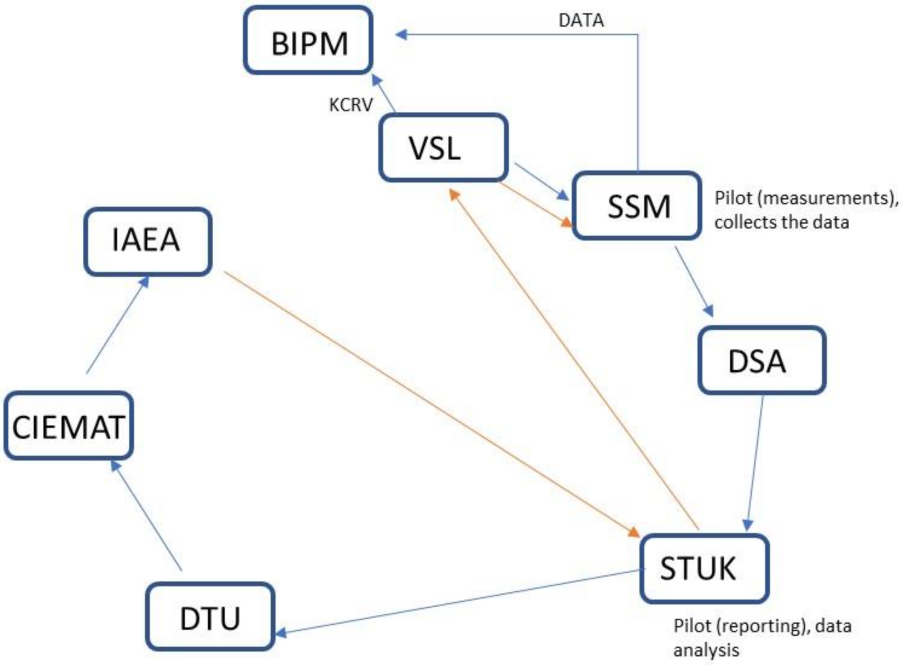

Figure 1. Schematic illustration of the comparison course.

Table 5. Proposed comparison events.

Event	Due date
DTU, STUK, and SSM ship transfer standard to VSL	October 12th, 2021
Comparison measurements (see table 4)	October 2021 – October 2022
Earliest results to be submitted to SSM	February 1st, 2022
Final due date for results to BIPM	October 15th, 2022
Chamber stability measurement reported (from SSM to STUK)	November 15th, 2022
Draft A delivered to participants	January 31st, 2022
Comments by the participants to draft A	March 31st, 2023
Draft B available	June 10th, 2023
Final report available	Depending upon comments by evaluators

5 References

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Appendix I: Complete addresses of the participants (used for shipment)

VSL/Netherlands

Postal address:

VSL, National Metrology Institute
Thijsseweg 11
2629 JA DELFT
The Netherlands

Contact person: Leon de Prez

Tel: +31 15 2691690
e-mail: ldprez@vsl.nl

SSM / Sweden

Postal address:

Swedish Radiation Safety Authority (SSM)
Riksmätplatsen
Solna Strandväg 122
171 54 SOLNA
Sweden

Contact person: Linda Persson

Tel: +46 70 917 66 71
e-mail: Linda.Persson@ssm.se

DSA / Norway

Postal address:

Norwegian Radiation Protection Authority (DSA)
Department of Emergency Preparedness and Response
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NO-1361 Østerås
Norway

Contact person: Per Otto Hetland

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e-mail: per.otto.hetland@dsa.no

STUK / Finland

Postal address 1 (February 2022):

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Radiation Metrology Laboratory
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00880 Helsinki
Finland

Postal address 2 (July/August 2022):

Radiation and Nuclear Safety Authority (STUK)
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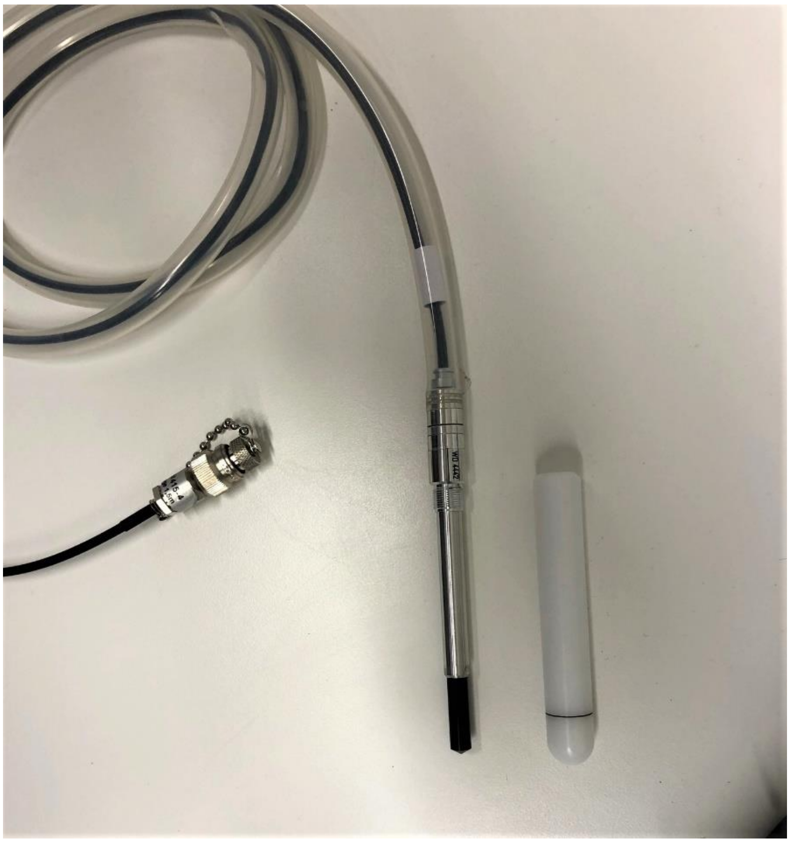
Appendix II. Pictures of transfer chambers.



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FC65G-3578

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