EURAMET Project 1389 SC

Bilateral Comparisons of air kerma and absorbed dose to water standards in ^{60}Co radiation beams for radiotherapy and air kerma standards in ^{137}Cs radiation beams for radiation protection between BEV (Austria) and VINS-VINCA (Serbia)

Technical Protocol

(submitted to EURAMET)

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1 Introduction on the subject and exact definition of the measurand(s) of the comparison

In the project, the comparisons for air kerma and for absorbed dose to water, both quantities measured in ^{60}Co radiation beams and for air kerma, measured in ^{137}Cs radiation beams, will take place in parallel. The comparison's aim is basically supporting VINS-VINCA SERBIA planned calibration and measurement capabilities (CMCs) of the quantities mentioned above in the context of the CIPM - Mutual Recognition Arrangement (CIPM-MRA).

The comparison is a follow-up of a review process done by the PTB in 2014 [1].

In order to do so, transfer standards for air kerma and absorbed dose to water are circulated among the participants. The circulating items are four ionization chambers and one dedicated electrometer. The participants will determine the calibration coefficients of the transfer standards $N_{K\mathrm{air}}$ and $N_{D\mathrm{w}}$ through comparison with their national standards in their respective ^{60}Co and ^{137}Cs beams. The calibration coefficients will be corrected to reference conditions as well as for leak current and saturation. No correction for polarity effects has to be applied as the ionisation chambers will be measured with a unique electrometer configuration for the polarity and the voltage level. Detailed uncertainty budgets for the calibration coefficient determinations will be given by the participants. All applied corrections to the calibration coefficient calculation will be documented in written form.

The measurements will be linked with the ongoing BIPM.RI(I)-K1, BIPM.RI(I)-K4 and BIPM.RI(I)-K5 comparisons through BEV [2], [3], [4].

Note: This protocol is following the structure given by [5].

The list of participants with the name of the contact persons are given in Table 1.

	Contact person	Country	Institute	E-mail adress
1	Dipl. Ing. Andreas Steurer	Austria	BEV	andreas.steurer@bev.gv.at
2	Djordje Lazarevic	Serbia	VINS	djordje.lazarevic@vinca.rs

Table 1 Participants

2 Description of the scheme/topology of the comparison

The ionization chambers will be checked by BEV. Then the calibration at BEV will be done. The next step is the calibration at VINS. Finally again the calibration will be done at BEV including a final check of the ionization chambers.

3 Stability check of the transfer standard, i.e. via measuring the standard at least in the beginning and the end by the same laboratory

The pilot laboratory will check and calibrate the ionization chambers before and after calibration at VINS.

4 Time schedule, in particular starting date and envisaged date of conclusion

The official start of the project was the registration at EURAMET in March 2016. The calibration time schedule is given in Table 2.

	Participant	Measurement duration at laboratory
1	BEV	July / August /September 2016
2	VINS	September / October / November 2016
3	BEV	November / December 2016

Table 2 Calibration time schedule

As described in section 12 the next steps are:

- Draft A report
- Draft B report
- Final report

The closing of the project is intended in autumn 2017.

5 Description of the transfer standard(s): producer, type, serial number, technical data needed for operation, stability statement, etc.

The circulating electrometer is a PTW UNIDOS 10002, SN 20478. The belonging ionization chambers are also from PTW.

The ionization chambers for Co-60 therapy level are not watertight. Therefore the use of a protecting PMMA-sleeve is necessary. The chambers are cylindrical (Farmer-type). Their technical data are given in Table 3. Each of these ionization chambers has its own build-up cap for the calibration in terms of air kerma and its own water protecting PMMA-sleeve for calibration in the water phantom in terms of absorbed dose to water. Every sleeve is marked with the direction to the focus and with the position of the chamber centre.

Type, serial number	Nominal volume	Collecting Voltage	Wall material	Waterproof	Outer Diameter build-up-cap	Outer Diameter PMMA-sleeve 4322/U13
PTW T30012, SN 0026	0,6 cm^3	+400 V	Graphite	No	16,46 mm	9,26 mm
PTW T30012, SN 0027	0,6 cm^3	+400 V	Graphite	No	16,46 mm	9,26 mm

Table 3 Technical data of the spherical ionization chambers for Co-60 therapy level

The ionization chambers for Cs-137 radiation protection level are spherical. Their technical data are given in Table 4. The necessary 2 mm PMMA plate is not included. It must be provided by the calibration laboratory.

Type, serial number	Nominal volume	Collecting Voltage	Wall material	Outer Diameter
PTW 32005 TK-30, SN 000136	27,9 cm^3	+400 V	POM $(CH_2O)_N$	44,4 mm
PTW 32002 1 l, SN 000592	1000 cm^3	+400 V	POM $(CH_2O)_N$	140 mm

Table 4 Technical data of the ionization chambers for Cs-137 radiation protection level

6 Advice on handling and organising the transport of the transfer standard

Each participant must arrange the transport of the system himself. The cost of dispatch and insurance including customs charges have to be covered by the participant who is sending to the other participant.

The transport container contains:

- Electrometer PTW UNIDOS 10002, SN 20478 including power cable
- 2 pieces cable PTW T26002.1.001-20 (extension cable, 20 m length)
- Ionization chamber PTW T30012, SN 0026 (including PMMA-Sleeve 4322/U13) in a case
- Ionization chamber PTW T30012, SN 0027 (including PMMA-Sleeve 4322/U13) in a case
- Ionization chamber PTW 32005 TK-30, SN 000136 in a case
- Ionization chamber PTW 32002 1 l, SN 000592 in a case
- Manual for electrometer PTW UNIDOS 10002 (User Manual UNIDOS, PTW - Universal Dosemeter, Firmware No. 2.20 and higher, for type 10001 (connecting system M), S/N ≥ 10620, for type 10002 (connecting system W=TNC), ≥ S/N 20232, for type 10005 (connecting system N=BNT), ≥ S/N 50070, D196.131.00/14 en 2009-04 Sa/Hn)
- Manual for ionization chamber PTW T30012 (User Manual Farmer Chamber, Ionization Chamber Type 30010, 30011, 30012, 30013, D596.131.00/05 en 2016-01 ext/Hn)
- Manual for ionization chambers PTW 32005 TK-30 and PTW 32002 1 l (User manual 1 l Spherical chamber Type 32002, 10 l Spherical chamber Type 32003, Spherical chamber TK30 Type 32005, D466.131.00/04 en, 2009-04 Sa/Hn)

7 Test to be carried out before measurements

The ionization chambers are connected to the electrometer which has to be switched on at least one hour before doing any measurements.

The electrometer mode is set to "∫ Current dt, Range LOW, Integration time 60 s" with a collecting voltage of +400 V. Then, first ten leak current measurements are acquired each with 60 s integration time, followed by the opening of the source and a 10 Gy pre-irradiation period. This is necessary for the therapy level ionization chambers. According to the manual a pre-irradiation of the radiation protection level ionization chambers is not necessary. Nevertheless 10 min pre-irradiation is recommended.

8 Handling of the transfer standard(s) at receipt and during measurements

After the receipt of the transfer measurement system the participant has to check the electrometer and the ionization chambers for damage and has to inform the pilot laboratory immediately about the arrival of the system and its condition.

The equipment has to be stored under safe and climatic controlled conditions.

9 Description of the used calibration method, measurement conditions and calibration points

9.1 Object of the comparison

The calibration of two ionization chambers against the national standards of air kerma and of absorbed dose to water in ^{60}Co beams (therapy level) and two ionization chambers against the national standards of air kerma in ^{137}Cs beams (radiation protection level) will be carried out.

The ionisation chambers will be used sequentially, each with the also circulating electrometer. The chambers are placed free in air for the air kerma measurements at the reference distance in the ^{60}Co and ^{137}Cs beams respectively and in water at the depth of 5 g/cm^2 for the absorbed dose to water measurements at the reference distance in the ^{60}Co beams where the conventional true values of air kerma and absorbed dose to water rates are established by the corresponding national standards. The calibration coefficients are calculated from

$$N_{K_\mathrm{a}} = \frac{\dot{K}_\mathrm{a}}{I_\mathrm{corr}} \tag{1}$$

respectively

$$N_{D_\mathrm{w}} = \frac{\dot{D}_\mathrm{w}}{I_\mathrm{corr}} \tag{2}$$

Meaning of the symbols:

N_{K_a} .... calibration coefficient for air kerma

$\dot{K}_\mathrm{a}$ .... established air kerma rate

N_{D_w} .... calibration coefficient for absorbed dose to water

$\dot{D}_\mathrm{w}$ .... established absorbed dose to water rate

I_corr .... measured ionisation current corrected to reference conditions as well as for leak current and saturation

9.2 Reference conditions

The chambers are basically placed in the usual reference configuration in the beams where the conventional true values of air kerma and absorbed dose to water rates are established.

The calibration coefficients of the ionisation chambers N_{K_a} and N_{D_w} be given in terms of air kerma and absorbed dose to water per unit charge in the units of Gy/C referring to reference conditions of air pressure, air or water temperature and relative humidity. These are:

$$p_0 = 101{,}325 \text{ hPa} \tag{3}$$

$$T_0 = 293{,}15\ K \tag{4}$$

$$h_0 = 50\ \%\text{rh} \tag{5}$$

Meaning of the symbols:

p_0.......................... air pressure at reference conditions

T_0 .... air or water temperature at reference conditions

h_0.......................... relative humidity at reference condition

In the case of deviating conditions for air or water temperature respectively and air pressure the usual correction has to be applied:

$$k_{pT} = \frac{p_0}{p} \cdot \frac{T}{T_0} \tag{6}$$

Meaning of the symbols:

k_{pT} .... correction factor to correct the deviation from reference conditions for air or water temperature respectively

p........................... real (measured) air pressure

T........................... real (measured) air or water temperature

The relative humidity of the environment should be between 20 % rh and 80 % rh, otherwise a correction to h = 50 % rh should be applied.

Definition of the reference point: All calibrations are performed with positioning the camber centre (half outer diameter) in the reference distance.

The calibration coefficients of the chambers shall be corrected further for leak current and saturation but not for polarity effects. The saturation correction may be either calculated or determined from adequate measurements according to the procedure normally used in the laboratory. The chosen method will be documented and reported with the results.

The chambers are measured with the accompanying electrometer PTW UNIDOS 10002, SN 20478 in the already defined configuration for the two chambers (Collecting voltage +400 V, mode "ò Current dt", Range LOW/MEDIUM (to be selected), integration time 60 s").

The chambers should be aligned in the beam with the black line on their stem facing the radiation source and the marking on the build-up cap being on the beam axis, both markings defining together the reference point of the chamber. Pictures of the chambers and the appropriate build-up caps and sleeve, if any, are shown in Appendix A.

Each laboratory uses its own temperature, pressure and humidity measurement equipment.

9.3 Calibration procedure

1st step: Determination of the air kerma and absorbed dose to water respectively

The national standard S is positioned in the radiation field with its reference point on the beam axis in the specified focus-detector-distance (*FDD*). The air kerma rate and the absorbed dose to water rate respectively are determined by the standard S.

$$\dot{K}_\mathrm{a} = I_\mathrm{corr,S} \cdot N_{K_\mathrm{a},\mathrm{S}} \text{ respectively } \dot{D}_\mathrm{w} = I_\mathrm{corr,S} \cdot N_{D_\mathrm{w},\mathrm{S}} \quad (7)$$

Meaning of the symbols:

$I_\mathrm{corr,S}$ .... Ionization current of national standard S (corrected to reference conditions)

$N_{K_\mathrm{a},\mathrm{S}}$, $N_{D_\mathrm{w},\mathrm{S}}$ .... Calibration coefficients of national standard S (Gy/C)

2nd step: Calibration of the transfer standard

The national standard is replaced by the transfer standard T with its reference point on the beam axis in the specified *FDD*.

The calibration coefficient of the transfer standard T in Gy/C is calculated with:

$$N_{K_\mathrm{a},\mathrm{T}} = \frac{\dot{K}_\mathrm{a}}{I_\mathrm{corr,T}} \text{ respectively } N_{D_\mathrm{w},\mathrm{T}} = \frac{\dot{D}_\mathrm{w}}{I_\mathrm{corr,T}} \quad (8)$$

Meaning of the symbols:

$N_{K_\mathrm{a},\mathrm{T}}$, $N_{D_\mathrm{w},\mathrm{T}}$ .... Calibration coefficient transfer standard T (Gy/C)

The participants will proceed in their own way to determine the calibration coefficients of the ionization chambers. Similarly to the uncertainty budgets detailed description of the procedure applied will be given.

9.3.1 Calibration procedure Co-60 therapy level air kerma

The chambers are placed in the usual reference configuration in the ^{60}Co beams where the conventional true values of air kerma rates are established.

Following the BIPM reference conditions [6] the focus-detector-distance (*FDD*), i.e. the distance between the chamber reference point and the focus point of the ^{60}Co source, is 100 cm along the central beam axis. A 10 cm x 10 cm beam cross section at the reference plane perpendicular to the beam axis and specified by the photon fluence rate at the mid-point of each side of the square being 50 % of the photon fluence rate at the centre is used. For the determination of N_{K_a} the chamber is placed free in air.

9.3.2 Calibration procedure Co-60 therapy level absorbed dose to water

The chambers are placed in the usual reference configuration in the ^{60}Co beams where the conventional true values of absorbed dose to water rates are established.

According to IAEA TRS 398 [7] the focus-detector-distance (*FDD*), i.e. the distance between the chamber reference point and the focus point of the ^{60}Co source, is 100 cm along the central beam axis. A 10 cm x 10 cm beam cross section at the reference plane perpendicular to the beam axis and specified by the photon fluence rate at the mid-point of each side of the square being 50 % of the photon fluence rate at the centre is used. For the determination of N_{D_w} the reference point of the chamber is placed at the depth of 5 g/cm^2 in a water phantom (30 cm x 30 cm x 30 cm).

9.3.3 Calibration procedure Cs-137 radiation protection level air kerma

The chambers are placed in the ^{137}Cs beams in a proper the focus-detector-distance (*FDD*), i.e. the distance between the chamber reference point and the focus point of the ^{60}Co source, where the conventional true values of air kerma rates are established.

The minimum focus-detector-distance (*FDD*) depends on size of the sectional area of the ionization chamber. Each laboratory is responsible to ensure that the radiation field is large enough for the sectional area of the ionization chamber to be calibrated. The radiation field is defined by the 50 % value of the photon fluence rate at the centre is used.

For the determination of N_{K_a} the chamber is placed free in air.

If secondary electron equilibrium is not ensured, a 2 mm PMMA plate - according to ISO 4037-3 [8] - must be positioned in front of the ionization chamber to ensure secondary electron equilibrium.

9.4 Calibration measurements at BEV

9.4.1 General

The Measurements at BEV are done in 2 steps:

<u>Step 1: Determination of the air kerma rate respectively absorbed dose to water rate reference value</u>

The Determination of the current air kerma rate respectively absorbed dose to water rate is done with BEV primary standard using BEV electrometer system

- for measurements with the Co-60 source (therapy level air kerma and absorbed dose to water): 2-channel electrometer system with 2 electrometer Keithley 6517
- for measurements with the Cs-137 sources (radiation protection level air kerma): self-made 2-channel electrometer DCI.2CH

<u>Step 2: Calibration with transfer chambers with the UNIDOS dedicated for the comparison</u>

The next step is the determination of the calibration coefficients of the transfer chambers measuring the charge with the electrometer UNIDOS dedicated for the comparison.

The procedure to prepare the electrometer is given in section 7.

After this procedure including pre-irradiation the electrometer is set to "ò Current dt, Range LOW, Integration time 60 s" with a collecting voltage of +400 V. To consider the leakage current, the zero balance is done following the manual. Then a test measuring without radiation after zero balance is done.

Thereafter, twenty-five irradiation measurements each with 60 s integration time are done. Air or water temperature and air pressure are measured at halftime of each 60 s integration period. The air density correction k_{pT} is applied to each acquired charge value. The calculated saturation correction k_S is also applied to each charge value.

Finally an additional test measuring without radiation after zero balance is done.

The mean of the corrected charging values is calculated. The ratio of the air kerma respectively the absorbed dose to water and the so calculated mean is the calibration factor.

$$N_{K_\mathrm{a},\mathrm{T}} = \frac{K_\mathrm{a}}{Q_\mathrm{corr,T}} \text{ respectively } N_{D_\mathrm{w},\mathrm{T}} = \frac{D_\mathrm{w}}{Q_\mathrm{corr,T}} \tag{9}$$

Meaning of the symbols:

K_a .... air kerma, obtained by integration of the established air kerma rate over the charging time

D_w........................ absorbed dose to water, obtained by integration of the established absorbed dose to rate over the charging time

$Q_\mathrm{corr,T}$ .... with the transfer equipment (UNIDOS plus transfer chamber) measured ionisation charge corrected to reference conditions as well as for leak current and saturation

9.4.2 Determination of the air kerma Co-60 therapy level

The air kerma rate for Co-60 is determined with the primary standards CC01-125 and CC01-132. These primary standards are cavity ionization chambers as described in the key comparison report [2]. This report is basis for the CMC-entry of BEV.

9.4.3 Determination of absorbed dose to water Co-60 therapy level

The absorbed dose rate for Co-60 is determined using a graphite calorimeter, which is a primary standard. It is described in [9] and [10]. The determined value of the absorbed dose rate to water was transferred to the cavity ionization chamber CC01-105 which is the basis for the current measurements. The determination of the absorbed dose rate to water is also described in the key comparison report [3]. This report is basis for the CMC-entry of BEV.

9.4.4 Determination of the air kerma Cs-137 radiation protection level

The air kerma rate for Cs-137 is determined with the primary standards CC01-125 and CC01-132. These primary standards are cavity ionization chambers as described in the key comparison report [4]. This report is basis for the CMC-entry of BEV.

9.5 Calibration measurements at VINS

9.5.1 General

The Measurements at VINS are done in 2 steps:

<u>Step 1: Determination of the air kerma rate or absorbed dose to water rate reference value</u>

Determination of reference values of air kerma rate and absorbed dose to water rate is done with VINS secondary standards, traceable through IAEA dosimetry laboratory to primary standard of BIPM. Following secondary standards are used:

- for measurements with the Co-60 source (therapy level, air kerma and absorbed dose to water): PTW 30012 chamber (farmer type) with PTW Unidos T10002 electrometer
- for measurements with the Cs-137 sources (radiation protection level, air kerma): PTW 32002 chamber (spherical litre chamber) with PTW Unidos T10002 electrometer

Step 2: Calibration with transfer chambers with the UNIDOS dedicated for the comparison

The next step is the determination of the calibration coefficients of the transfer chambers measuring the charge with the electrometer UNIDOS dedicated for the comparison.

The procedure to prepare the electrometer is given in section 7.

After this procedure including pre-irradiation the electrometer is set to "∫ Current dt, Range LOW, Integration time 60 s" with a collecting voltage of +400 V. To consider the leakage current, the zero balance is done following the manual. Then a test measuring without radiation after zero balance is done.

Thereafter, twenty-five irradiation measurements each with 60 s integration time are done. Air or water temperature and air pressure are measured at halftime of each 60 s integration period. The air density correction k_{pT} is applied to each acquired charge value. The calculated saturation correction k_S is also applied to each charge value.

Finally an additional test measuring without radiation after zero balance is done.

The mean of the corrected charging values is calculated. The ratio of the air kerma respectively the absorbed dose to water and the so calculated mean is the calibration factor.

$$N_{K_\mathrm{a},\mathrm{T}} = \frac{K_\mathrm{a}}{Q_\mathrm{corr,T}} \text{ respectively } N_{D_\mathrm{w},\mathrm{T}} = \frac{D_\mathrm{w}}{Q_\mathrm{corr,T}} \qquad (10)$$

Meaning of the symbols:

K_a .... air kerma, obtained by integration of the established air kerma rate over the charging time

D_w .... absorbed dose to water, obtained by integration of the established absorbed dose to rate over the charging time

$Q_\mathrm{corr,T}$ .... ionisation charge measured with the transfer equipment (UNIDOS plus transfer chamber) corrected to reference conditions as well as for leak current and saturation

9.5.2 Determination of the air kerma Co-60 therapy level

The air kerma rate for Co-60 is determined with the secondary standard PTW 30012 with electrometer PTW Unidos T10002.

9.5.3 Determination of absorbed dose to water Co-60 therapy level

The absorbed dose rate for Co-60 is determined with the secondary standard PTW 30012 with electrometer PTW Unidos T10002.

9.5.4 Determination of the air kerma Cs-137 radiation protection level

The air kerma rate for Cs-137 is determined with the secondary standard PTW 32002 with electrometer PTW Unidos T10002.

10 Presentation of the results

10.1 Content

For every chamber and every measurement quantity an Excel-Sheet will be prepared by BEV to collect the data. These Excel-Sheets will contain:

- air kerma rate respectively absorbed dose to water rate
- range of the environmental conditions during the measurements (T, p and h)
- uncorrected charge for the measuring time of 60 s
- resulting corrected charge $Q_{\mathrm{corr,T}}$ and resulting ionization current
- applied correction factors (e.g. air density correction factor, recombination correction factor)
- resulting calibration coefficient in Gy/C
- measurement setup data
- focus-detector-distance (*FDD*)
- radiation field size in focus-detector-distance (*FDD*)
- identification of the radioactive source, current activity
- setting data Unidos
- uncertainty data

10.2 Handling and evaluation of the results

VINS will send its results with detailed descriptions of the procedures, the applied model functions and uncertainty budgets to the pilot laboratory by email within one month after having finished its measurements.

BEV will evaluate the comparison on the basis of the results reported by the participants.

The comparison of the arithmetic means of each calibration will be done by calculation of the ratio of BEV-value and VINS-value.

$$R_{K_\mathrm{a}} = \frac{N_{K_\mathrm{a},\mathrm{T,BEV}}}{N_{K_\mathrm{a},\mathrm{T,VINS}}} \text{ respectively } R_{D_\mathrm{w}} = \frac{N_{D_\mathrm{w},\mathrm{T,BEV}}}{N_{D_\mathrm{w},\mathrm{T,VINS}}} \tag{11}$$

Meaning of the symbols:

R_{K_a} , R_{D_w} ....ratios of the calibration factor obtained by BEV and VINS

The values of VINS will be linked to the KCRVs (key comparison reference values) based on the key comparisons of BEV.

10.3 Publication of the results

BEV, as the pilot laboratory, will prepare a Draft A report being sent for comments and discussion to VINS. Then an arranged Draft B report will be sent to EURAMET for consultation.

The revised Draft B report will be produced as the official final report of the EURAMET project. It will be submitted to the EURAMET TC IR Chair to publish it on the EURAMET website.

11 List of the principal components of the uncertainty budget

Each participant will deliver detailed uncertainty budgets for the calibration coefficient determinations of the transfer standards in accordance with the ISO Guide to the expression of uncertainties in measurements [11].

The proposed model function for the 1st calibration step is:

$$\dot{K}_{\mathrm{a}} = I_{\mathrm{S}} \cdot N_{K_{\mathrm{a}},\mathrm{S}} \cdot k_{pT} \cdot k_{\mathrm{s,S}} \cdot k_{\mathrm{r,S}} \text{ respectively } \dot{D}_{\mathrm{w}} = I_{\mathrm{S}} \cdot N_{D_{\mathrm{w}},\mathrm{S}} \cdot k_{pT} \cdot k_{\mathrm{s,S}} \cdot k_{\mathrm{r,S}} \qquad (12)$$

Meaning of the symbols:

I_{S} .... Uncorrected ionization current national standard S

$k_{\mathrm{s,S}}$ .... Recombination correction factor national standard S

$k_{\mathrm{r,S}}$ .... Correction factor to correct the deviation between the nominal *FDD* and the real *FDD* by positioning the national standard S

Usually $k_{\mathrm{r,S}} = 1$ is used. The possible deviation is considered by the uncertainty.

Note: In the case of the integrating mode using the electrometer UNIDOS $\dot{K}_{\mathrm{a}}$ has to be replaced with the air kerma K_{a} respectively $\dot{D}_{\mathrm{w}}$ with the absorbed dose to water D_{w} and the ionization currents I_{S} and I_{T} with the charge Q_{S} and the charge Q_{T}.

The uncertainty budget of the 1st step is given in Table 5.

Input quantity	Symbol	$u_{i,\mathrm{A}}$	$u_{i,\mathrm{B}}$	$u_{i,\mathrm{A}}^2 + u_{i,\mathrm{B}}^2$
Calibration coefficient of the national standard S	$N_{K_{\mathrm{a}},\mathrm{S}}$, $N_{D_{\mathrm{w}},\mathrm{S}}$			
Ionization current of the national standard S	I_{S}			
Air density correction factor	k_{pT}			
Recombination correction factor national standard S	$k_{\mathrm{s,S}}$			
Position of the national standard S	$k_{\mathrm{r,S}}$			
Determined air kerma rate respectively absoerbed dose to water rate	$\dot{K}_{\mathrm{a}}$, $\dot{D}_{\mathrm{w}}$	$u = \sqrt{\sum_i \left(u_{i,\mathrm{A}}^2 + u_{i,\mathrm{B}}^2\right)} =$		

Table 5 Uncertainty calculation for 1st step of the calibration procedure (determination of the air kerma respectively absorbed dose to water rate)

The proposed model function for the 2nd calibration step is:

$$N_{K_{\mathrm{a}},\mathrm{T}} = \frac{\dot{K}_{\mathrm{a}}}{I_{\mathrm{T}} \cdot k_{pT} \cdot k_{\mathrm{s,T}} \cdot k_{\mathrm{r,T}}} \text{ respectively } N_{D_{\mathrm{w}},\mathrm{T}} = \frac{\dot{D}_{\mathrm{W}}}{I_{\mathrm{T}} \cdot k_{pT} \cdot k_{\mathrm{s,T}} \cdot k_{\mathrm{r,T}}} \qquad (13)$$

Meaning of the symbols:

I_{T} .... Uncorrected ionization current transfer standard T

$k_{\mathrm{s,T}}$ .... Recombination correction factor transfer standard T

$k_{\mathrm{r,T}}$ .... Correction factor to correct the deviation between the nominal *FDD* and the real *FDD* by positioning the transfer standard T

Usually $k_{\mathrm{r,T}} = 1$ is used. The possible deviation is considered by the uncertainty.

The uncertainty budget of the 2nd step is given in Table 6.

Input quantity	Symbol	$u_{i,\mathrm{A}}$	$u_{i,\mathrm{B}}$	$u_{i,\mathrm{A}}^2 + u_{i,\mathrm{B}}^2$
Determined air kerma respectively absorbed dose to water	$\dot{K}_\mathrm{a}$, $\dot{D}_\mathrm{w}$			
Ionization current of the transfer chamber T	I_T			
Air density correction factor	k_{pT}			
Recombination correction factor national standard T	$k_{\mathrm{s,T}}$			
Position of the transfer standard T	$k_{\mathrm{r,T}}$			
Calibration coefficient of the transfer standard T	$N_{K_\mathrm{a},\mathrm{T}}$, $N_{D_\mathrm{w},\mathrm{T}}$	$u = \sqrt{\sum_i \left(u_{i,\mathrm{A}}^2 + u_{i,\mathrm{B}}^2\right)} =$		
		$U = 2 \cdot u =$		

Table 6 Uncertainty calculation for 2nd step of the calibration procedure (calibration coefficient transfer chamber)

12 Timetable for communicating the results

The evaluation of the results will be done by BEV in January / February 2017. The finishing of Draft A of the report is scheduled in March / April 2017. The review process of Draft B should be done in summer 2017. The final report should be sent to EURAMET in autumn 2017.

13 Principle of evaluation of the results and linkage mechanism to the corresponding KCRV

BEV will evaluate the results of measurements and will calculate the ratios of the calibrations coefficients determined by both laboratories for every quantity.

The results of the comparison are linked to the KRCVs (key comparison reference values) based an the key comparisons of BEV

- BIPM.RI(I)-K1: Measurement of Air Kerma for Cobalt 60 [2]
- BIPM.RI(I)-K4: Measurement of Absorbed Dose to Water for Cobalt 60 [3]
- BIPM.RI(I)-K5: Measurement of Air Kerma for Cesium 137 [4]

and the relating CMC-entries of BEV.

14 Financial aspects, e.g. transportation or costs for transfer standard if applicable

The transport of the transfer measuring equipment from BEV to VINS will be carried out and financed by BEV. Insurance is obligatory. BEV is responsible to get the necessary carnet documents.

The transport of the transfer measuring equipment back to BEV from VINS will be carried out and financed by VINS. Insurance is obligatory.

The value for the insurance of the equipment, including the transfer chamber is about 17450 €.

Quantity	Item	Weight	Worth
1	Electrometer PTW UNIDOS 10002, SN 20478 including power cable	8 kg	7000,00 €
2	Cable PTW T26002.1.001-20 (extension cable, 20 m length)	1 kg	1000,00 €
1	Ionization chamber PTW T30012, SN 0026 (incl. PMMA-Sleeve 4322/U13) in a case	0,5 kg	2000,00 €
1	Ionization chamber PTW T30012, SN 0027 (incl. PMMA-Sleeve 4322/U13) in a case	0,5 kg	2000,00 €
1	Ionization chamber PTW 32005 TK-30, SN 000136 in a case	1,5 kg	2200,00 €
1	Ionization chamber PTW 32002 1 l, SN 000592 in a case	4 kg	3000,00 €
1	Transport box, 743 mm x 533 mm x 430 mm (137 l)	8 kg	250,00 €
	Sum:	23,5 kg *)	17450,00 €
*) Excluding packing material; including filling packing approximately 26 kg			

Table 7 Data for insurance and carnet

15 Reference to useful documents

[1] Report on the PTB project "Support of the Quality Infrastructure in Serbia" with the title "Fact Finding Mission to Vinča Institute of Nuclear Sciences, Department of Radiation and Environmental Protection, Belgrade: Support to the international recognition of measurement capabilities", 01.-03.12.2014.

[2] Kessler C., Allisy-Roberts P.J., Steurer A., Tiefenboeck W., Gabris F.: "Comparison of the standards for air kerma of the BEV and the BIPM for ^{60}Co gamma radiation", Metrologia 47 (2010), Tech.Suppl. p. 06006.

[3] Kessler C., Allisy-Roberts P.J., Steurer A., Baumgartner A., Tiefenboeck W., Gabris F.: "Comparison of the standards for absorbed dose to water of the BEV, Austria, and the BIPM for ^{60}Co gamma radiation", Metrologia 47 (2010), Tech.Suppl. p. 06017.

[4] Kessler C., Allisy-Roberts P.J., Steurer A., Tiefenboeck W., Gabris F., 2010, "Comparison of the standards for air kerma of the BEV and the BIPM for ^{137}Cs gamma radiation", BIPM.RI(I)_K5_Report, Paris, 2010-01-14, Metrologia 47 (2010) Tech.Suppl. p.06007

[5] EURAMET Guide No. 4, EURAMET Guide on Comparisons, Version 1.0 (05/2016)

[6] Allisy-Roberts P.J., Burns D.T. and Kessler C., 2007, Measuring conditions used for the calibration of ionization chambers at the BIPM, Rapport BIPM-07/06, 20 pp.

[7] IAEA, TRS No. 398, Absorbed Dose Determination in External Beam Radiotherapy, IAEA, VIENNA, 2000, ISSN 1011–4289, June 2006 (V.12)

[8] International Organization for Standardization. X and gamma reference radiations and calibrating dosemeters and doserate meters and for determining their response as a function of photon energy - Part 3: calibration of area and personal dosemeters and the measurement of their response as a function of energy and angle of incidence. ISO 4037–3 (Geneva: ISO) (1999).

[9] Witzani J., Duftschmid K.E., Strachotinsky Ch. & Leitner A.: A Graphite Absorbed-Dose Calorimeter in the Quasi-Isothermal Mode of Operation, Metrologia 20, 73-79 (1983), Springer-Verlag

[10] Baumgartner A., Steurer A., Tiefenböck W., Gabris F. Maringer F.J., Kapsch R.P. & Stucki G.: "Re-evaluation of correction factors of a primary standard graphite calorimeter in ^{60}Co gamma ray beams as a basis for the appointment of the BEV absorbed dose rate to water reference value", Radiation Protection Dosimetry (2010), pp. 1-10

[11] BIPM, JCGM 100:2008, Evaluation of measurement data - Guide to the expression of uncertainty in measurement (GUM 1995)

16 Appendix

16.1 Pictures of the electrometer, the ionization chambers and the packing

Figure 1 Electrometer PTW UNIDOS 10002, SN 20478

Figure 2 Extension cable PTW T26002.1.001-20 (20 m length)

Figure 3 Ionization chamber PTW T30012, SN 0026, including PMMA-Sleeve 4322/U13 and case

Figure 4 Ionization chamber PTW T30012, SN 0027, including PMMA-Sleeve 4322/U13 and case

Figure 5 Ionization chamber PTW 32005 TK-30, SN 000136 and case

Figure 6 Ionization chamber PTW 32002 1 l, SN 000592 and case

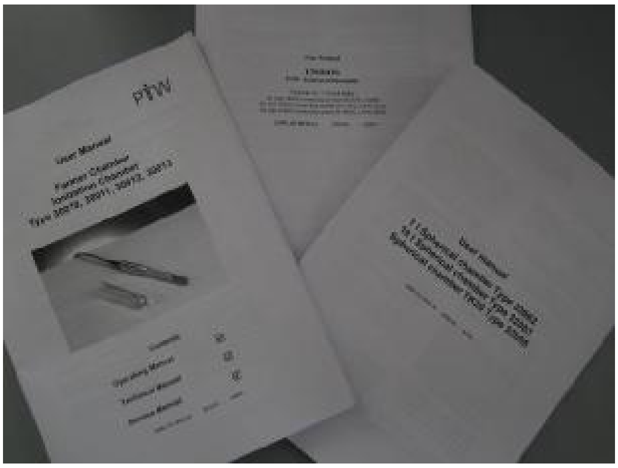

Figure 7 Manuals electrometer Unidos 10002, Ionization chamber PTW 30012, Ionization chambers 32005 TK-30 and PTW 32002 1 l

Figure 8 Transport box

Figure 9 Transport box and content

16.2 Packing list

Quantity	Item	Checking
1	Transport box, 743 mm x 533 mm x 430 mm (137 l)	
1	Electrometer PTW UNIDOS 10002, SN 20478 including power cable	
1	Ionization chamber PTW 32002 1 l, SN 000592 in a case	
1	Ionization chamber PTW T30012, SN 0026 (incl. PMMA-Sleeve 4322/U13) in a case	
1	Ionization chamber PTW T30012, SN 0027 (incl. PMMA-Sleeve 4322/U13) in a case	
1	Ionization chamber PTW 32005 TK-30, SN 000136 in a case	
3	Manuals (electrometer, ionization chambers)	
2	Cable PTW T26002.1.001-20 (extension cable, 20 m length)	

Table 8 Packing list

16.3 Pictures of the BEV measuring setups

16.3.1 Absorbed dose to water, therapy level

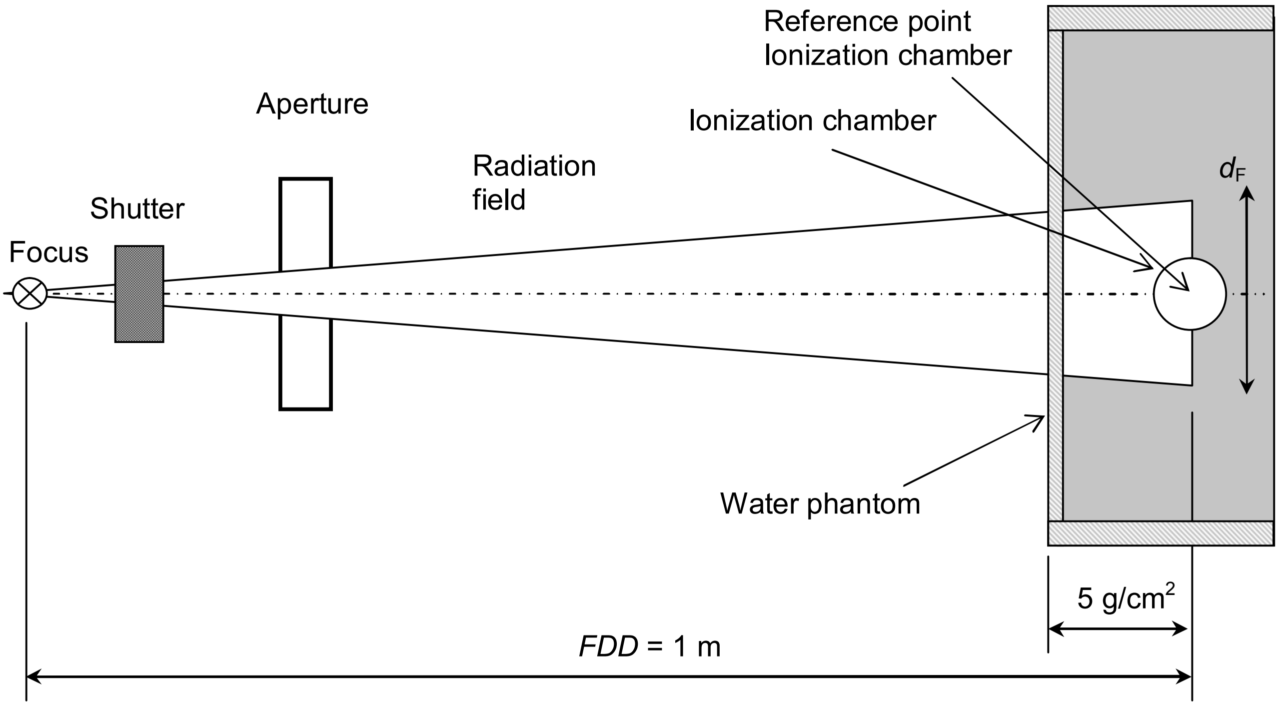

Figure 10 Schema of measurement setup for absorbed dose to water, therapy level Co-60

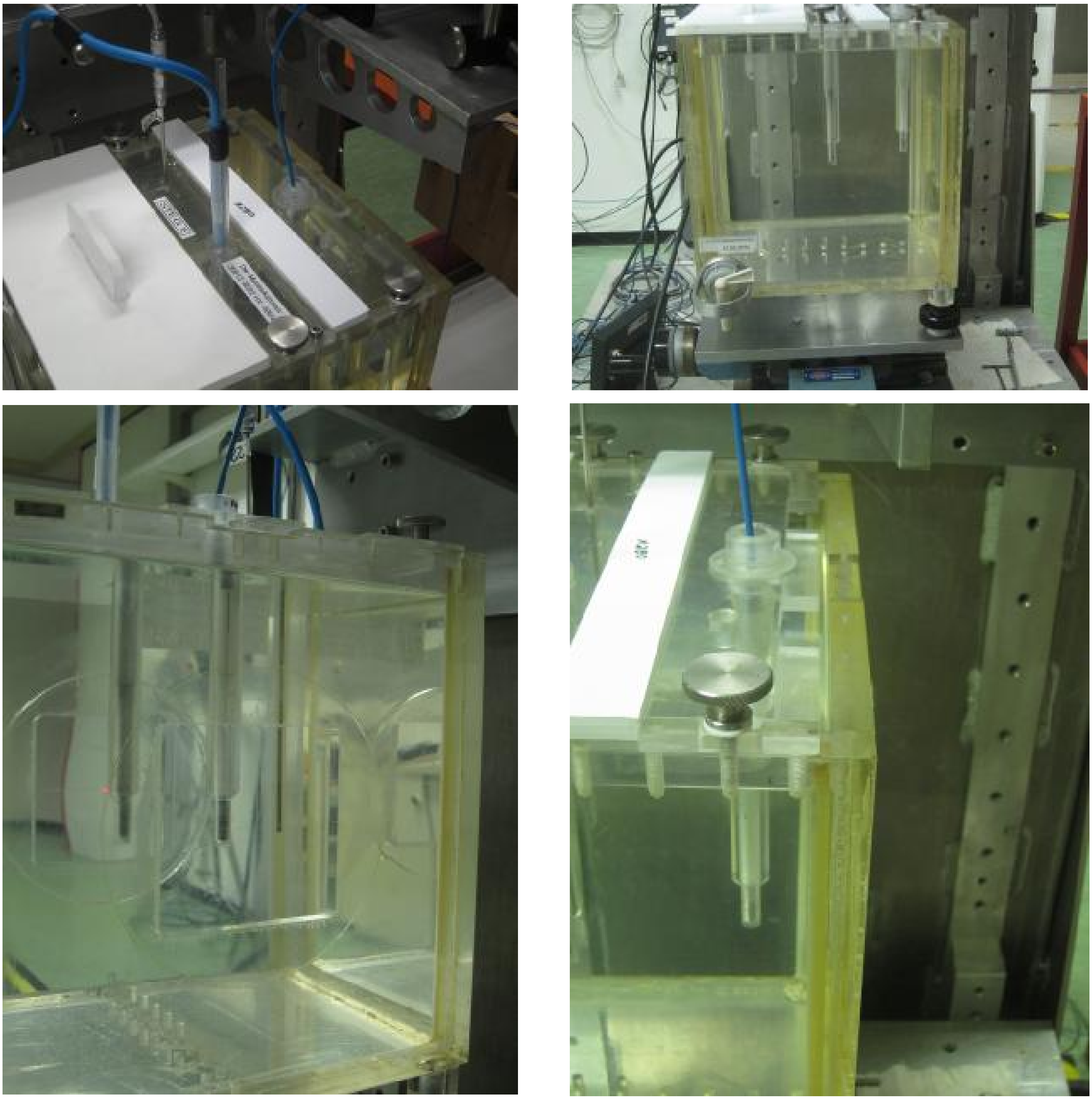

Figure 11 Absorbed dose to water, therapy level Co-60, ionization chamber PTW T30012 in the 30 cm x 30 cm x 30 cm water phantom including temperature sensor

16.3.2 Air kerma, therapy level

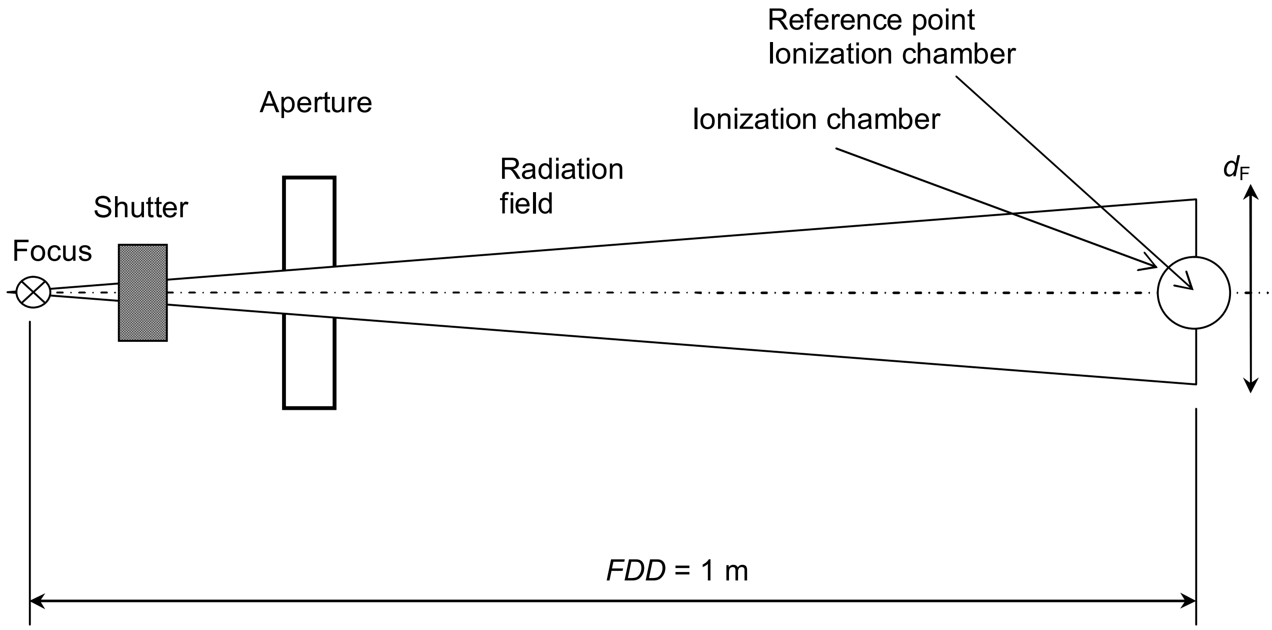

Figure 12 Schema of measurement setup for air kerma, therapy level Co-60

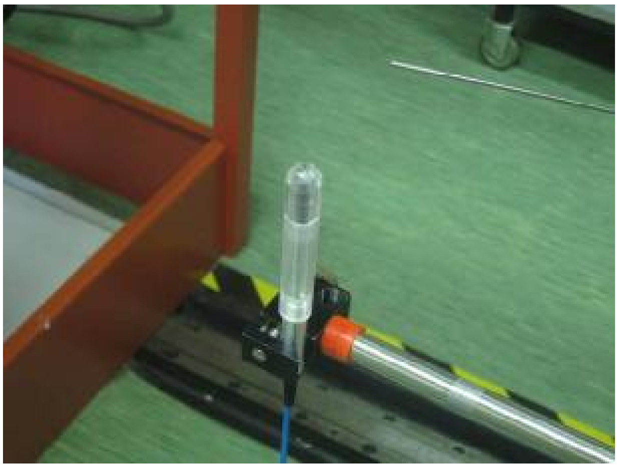

Figure 13 Air kerma, therapy level Co-60, ionization chamber PTW T30012 including temperature sensor

16.3.3 Air kerma, radiation protection level

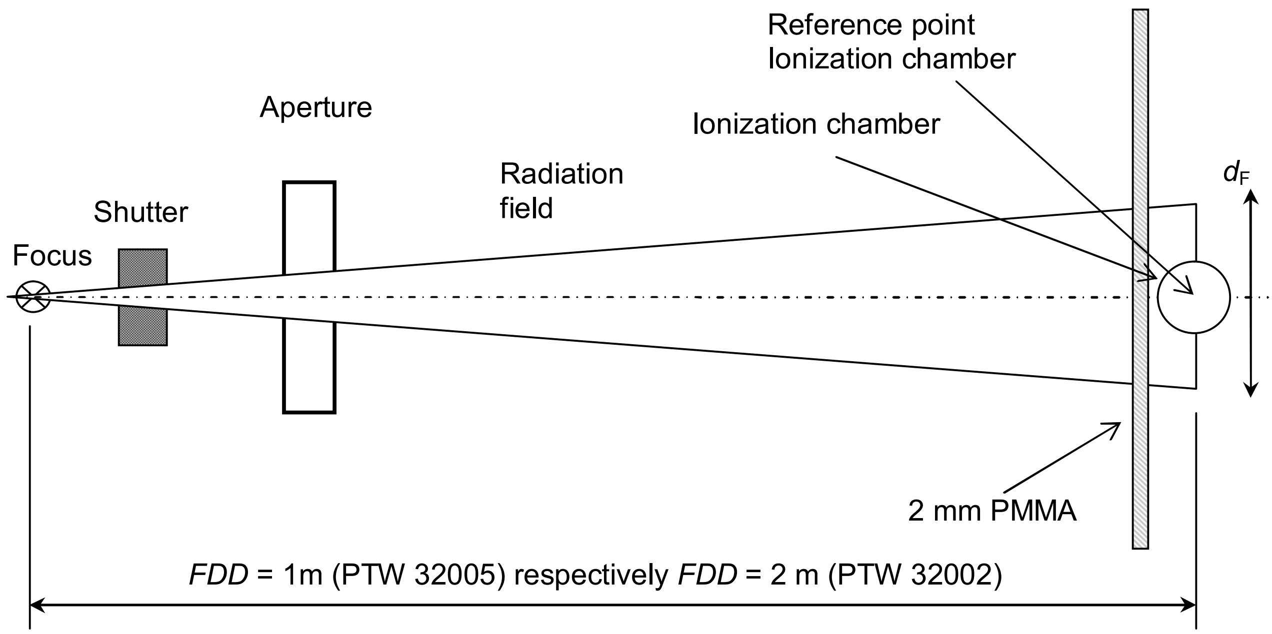

Figure 14 Schema of measurement setup for air kerma, radiation protection level Cs-137

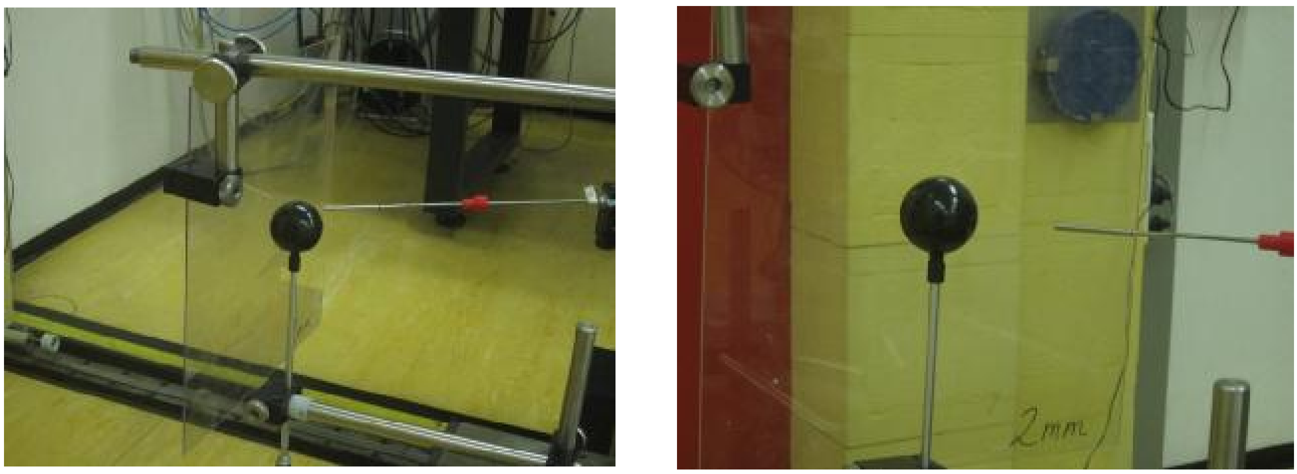

Figure 15 Air kerma, radiation protection level Cs-137, ionization chamber PTW 32005 TK-30, including 2 mm PMMA plate and temperature sensor

Figure 16 Air kerma, radiation protection level Cs-137, ionization chamber PTW 32002 1 l, including 2 mm PMMA plate and temperature sensor

16.4 Delivery addresses of the participants

	Institute	Delivery address
1	BEV	Dipl. Ing. Andreas Steurer BEV - Bundesamt für Eich- und Vermessungswesen Gruppe Eichwesen Abteilung E1 - Elektrizität und Strahlung, Referat Ionisierende Strahlung, Radioaktivität Arltgasse 35 1160 Wien Austria Phone: +43 1 21110-6379 Fax: +43 1 21110-6000 Phone Secretariate: +43 1 21110-6320 E-mail: andreas.steurer@bev.gv.at
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Table 9 Delivery addresses of the participants