EURAMET TC Project
Final Report

Project Title

Bilateral comparison of the H*(10) calibration coefficients for photon radiation

Coordinator, Institute, Country

Amra Šabeta, IMBiH (Bosnia and Herzegovina)

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EURAMET Bilateral comparison of the H*(10) calibration coefficients for photon radiation

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February 2024

Amra Šabeta
IMBiH, Institute of Metrology of Bosnia and Herzegovina

Hayo Zutz
PTB, Physikalisch-Technische Bundesanstalt

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1. Introduction

International Committee for Weights and Measures (CIPM) Mutual Recognition Arrangement (MRA) is a multilateral agreement between National Metrology Institutes (NMI) and Designated Institutes (DI). CIPM MRA provides mutual recognition of calibration and test certificates and national measurement standards. Key and supplementary comparisons are organized within CIPM MRA framework to support member Calibration and Measurement Capabilities (CMC) [1].

Ambient dose equivalent/rate, $H^*(10)$, is an operational quantity used in ionizing radiation dosimetry for area monitoring. It was introduced by ICRU [2] and adopted by European Union in Council Directives 96/29/EURATOM and 2013/59/EURATOM. A EURAMET supplementary comparison of calibration coefficients for $H^*(10)$ for photon radiation, EURAMET.RI(I)-S11, was organized between 2013 and 2014, with 16 NMIs and DIs and the International Organization taking part [3]. However, IMBIH is an NMI that still does not have published CMCs for $H^*(10)$, so there was a need to organize bilateral comparison to validate this quantity.

The aim of this comparison was to compare calibration coefficients for $H^*(10)$ for photon radiation. For this purpose, a transfer chamber was used. The comparison was performed for S-Cs, N-40, N-80, N-100, N-200 and N-300 radiation qualities established in accordance with ISO 4037:1 [4].

Agreed dose rates used were within the range between 5 mSv/h and 10 mSv/h.

This comparison can be used to validate calibrations in ambient dose equivalent/rate. Due to the similar calibration procedures, calibrations in personal dose equivalent/rate penetrating and superficial can also be validated by this comparison.

This comparison is intended to validate calibrations in qualities S-Cs, N-series from N-40, up to N-300. The comparison was performed for N-series X-ray radiation qualities, but calibrations in other standard qualities established in accordance with ISO 4037:1 [4] (H-series, W-series, L-series) use similar procedures, so the comparison can be appropriate for validation of these additional radiation qualities.

The comparison was coordinated by IMBiH as the pilot laboratory. PTB provided the transfer chamber. Results were evaluated by IMBiH. Final report was sent to TC-IR chair.

This comparison protocol was prepared according to EURAMET guidelines [5].

2. Participants

The following NMIs took part in the comparison:

- PTB - Physikalisch-Technische Bundesanstalt and
- IMBiH - Institute of Metrology of Bosnia and Herzegovina

3. Transfer standard

PTB *H(10)** ionization chamber was selected for the comparison. The chamber is shown in Figure 1. The chamber is of spherical shape and has a nominal volume of 1 l. The outer diameter of the chamber is 140 mm. Chamber voltage should be set to +300 V and applied to the collecting electrode (inner electrode).

The chamber has Triax PTW Connector (M Type) for current measurement and chamber voltage.

Figure 1: *PTB transfer chamber, S/N: 727- [6]*

4. Linearity of the transfer chamber

The participants agreed on a dose rate range, where the linearity correction is expected to be negligible: 5 mSv/h to 10 mSv/h. Dose rates during the comparison were between 5.41 mSv/h to 6 mSv/h.

5. Stability of the transfer chamber

Stability of the transfer chamber was checked by performing calibrations in all radiation qualities. PTB performed the stability check calibrations before sending the chamber to IMBiH and after return of the chamber.

6. Tests and procedures that were carried out before measurements

Transfer standard was used with the electrometers provided by the participants.
The participants were instructed as follows:
˝The measurement system should be left in the measurement room to reach thermal equilibrium, preferably overnight. Also, the transport container should be left closed during this process, especially in cold weather. The transfer chamber should be used according to installation instructions provided inside the transport container. The electrometer has to be switched on at least one hour before measurements and chamber should be used with a collecting voltage of +300 V applied to the collecting electrode (inner electrode). Even though pre-irradiation of protection level chambers is not necessary, pre-irradiation for at least 10 minutes was recommended. Before measurements, measurement system should be zeroed and at least 10 leakage measurements taken to ensure that the leakage current is less than 0.1 % of the anticipated signal.˝

7. Calibration method, calibration conditions

Comparison of calibration coefficients was performed for S-Cs, N-40, N-80, N-100, N-200 and N-300 radiation qualities realized in accordance with ISO 4037-1 [4]. Participants performed reference measurements in terms of air kerma free-in-air. The participants then stated the conversion coefficients used and the method of their determination. (e.g. spectrometry or ISO 4037:3 [7]). Recommended dose rate around 6 mSv/h (range: 5 mSvh^{-1} - 10 mSvh^{-1}).

The results are reported as received from the participants and they are presented as an appendix to the comparison (Annex B) In addition, values of conversion coefficients used by each individual partner for each radiation quality are reported in Tables 5 to 10, for future reference.

In the reference orientation, the chamber is oriented in such way that the red line on the stem points towards the radiation source. Reference point is the geometrical center of the sensitive volume of the chamber. The air-kerma rate at the point of test should not vary by more than 5 % over the entire sensitive volume of the transfer chamber. The chamber must be irradiated completely. Chamber readings were corrected for air density (reference conditions: air pressure 101.325 kPa, ambient temperature 20.0 °C, relative air humidity 65 %). Leakage current correction must be performed if leakage is higher than 0.1 % of the signal. Additional corrections were performed according to the procedures of participants. Correction for polarity effects was not necessary, because the transfer chamber was used with a unique configuration for the polarity and voltage, as stated in section 3).

The calibration coefficient in Sv/C is given by

$$N_{\mathrm{H}} = \frac{H^*(10)}{Q_{cor}} \quad (1)$$

where $H^*(10)$ is the conventional true value of ambient dose equivalent and Q_{cor} collected charge for transfer standard measurements, corrected to the reference conditions and determined as a product of air kerma and conversion coefficients ($H^*(10) = Ka * h_K(10;N)$).

Each participants prepared the calibration report which includes the following data: method of determination of H*(10), description of equipment used, description and pictures of calibration setup, determination of calibration coefficients and uncertainty budgets for each radiation quality and any correction used.

The measurement results and uncertainty budgets were reported in the excel form provided by IMBiH. The uncertainty was determined in accordance with the BIPM Guide to the expression of uncertainties in measurements [9]. Principal uncertainty components are shown in Table 1. Participants should list all other significant contributions to the uncertainty. All contributions to the overall uncertainty which are lower than 0.1 % (k = 1) may be neglected. National/reference standard stability should be reported as calibration coefficient uncertainty type A.

Table 1: *Uncertainty budget reporting form*

Source of uncertainty	$u_{i,\mathrm{A}}$	$u_{i,\mathrm{B}}$	$u_{i,\mathrm{A}}^2 + u_{i,\mathrm{B}}^2$	**Comment**
Reference *H*(10)* measurements				
Calibration coefficient of the national / reference standard				
Long term stability of reference standard				
Nonlinearity of electrometer sensitivity				
Change in source position				
Radiation beam quality				
Positioning reference instrument at a distance				
Collected charge / ionization current (repeatability)				
Resolution				
Leakage current				
Air density correction				
Temperature difference of the chamber				
Pressure difference of the chamber				
Conversion coefficient				
Other sources of uncertainty				
Combined uncertainty, *H*(10)*				
Transfer chamber measurements				
Homogeneity and field size				
Collected charge / ionization current (repeatability)				
Resolution				
Leakage current				
Positioning transfer instrument at a distance				
Air density correction				
Temperature difference of the chamber				
Pressure difference of the chamber				
Other sources of uncertainty				
Combined uncertainty, *Q/I*				
Combined uncertainty, N_H	$u = \sqrt{\sum_i \left(u_{i,\mathrm{A}}^2 + u_{i,\mathrm{B}}^2\right)} =$			

8. Calculation of the Comparison Reference Value and evaluation of the comparison results

The comparison reference value CRV was taken as the calibration coefficients, N_H, reported by PTB with traceability to their own primary standard for K_a or $H^*(10)$.

The uncertainty of CRV, u(CRV) is the reported uncertainty of the calibration coefficients, N_H.

The Degrees of Equivalence with the comparison reference value were evaluated by calculating the deviation from the comparison reference value (d_i) and the expanded uncertainty of that deviation. The deviation was calculated by applying the formula: $d_i = N_{Hi} – CRV$.

In this comparison, uncertainty due to the stability of the transfer chamber, evaluated as the standard deviation of 2 calibrations performed in PTB (SC), is added to the uncertainty.

For participants contributing to the CRV, the uncertainty of d_i is calculated according to equation:

$$u(d_i)^2 = u_i^2 - u(CRV)^2 + u^2_{SC} \quad (2)$$

In case of secondary standards laboratories , any possible correlations are disregarded, and $u(d_i)$ is evaluated according to equation:

$$u(d_i)^2 = u_i^2 + u(CRV)^2 + u^2_{SC} \quad (3)$$

Finally, for the presentation of the results, relative deviation and associated uncertainty were used, denoted as $D_i = 100 \cdot d_i / CRV$ and $u(D_i) = 100 \cdot u(d_i) / CRV$.

Correlation between IMBiH laboratory and the CRV was not evaluated. Regarding the traceability for air kerma for N-series qualities, IMBiH is traceable to PTB through IAEA. The contribution of the uncertainty of the calibration coefficient of the reference standard to the uncertainty of the calibration coefficient of the transfer instrument is very small, because of the high uncertainty in the conversion coefficient. This contribution is below 10 % of the total uncertainty, as can be calculated from the data in Annex A. Traceability for each participant is given in Table 2.

Table 2: *Traceability, as reported by participants*

Participant	Traceability in terms of *K*a					
	N-40	**N-80**	**N-100**	**N-200**	**N-300**	**S-Cs**
PTB	PTB	PTB	PTB	PTB	PTB	PTB
IMBiH	PTB through IAEA	PTB through IAEA	PTB through IAEA	PTB through IAEA	PTB through IAEA	BIPM through IAEA

9. Organization and time schedule

The comparison had 2 participants in total. The comparison started in PTB in October 2021 and the measurements were finished in March 2022. The calibration results were reported to the TC-IR chair as comparison reference value within 1 month after having finished the measurements and they also serve as the first point for stability checks.

PTB sent transfer chamber to IMBiH for calibration. After IMBiH performed measurements, transfer chamber was returned to PTB, and PTB performed measurements again to test chamber stability.

The planned comparison time schedule is shown in Table 3.

Table 3: *Time schedule*

September	21	PTB
October	21	IMBiH
November	21	PTB

During the comparison, there were some delays due to changes in protocol and final approval of the protocol by TC-IR, which was finalized on 23.09.2021. IMBIH finished measurements in January 2022. Measurements at IMBIH took longer due to holiday season and COVID-19 situation where laboratory had to be closed. Another set of measurements was performed at PTB in end of February beginning of March 2022.

The actual measurement schedule is shown in Table 4.

Table 4: *Actual time schedule*

October	21	PTB
January	22	IMBiH
March	22	PTB

10. Results for radiation quality N-40

Results of the intercomparisons for N-40 radiation quality are presented in Table 5. All uncertainties in the table are expanded uncertainties, with coverage factor k = 2. For the purpose of this comparison, **it is considered that the uncertainty reported by the participant is confirmed if the following is true: $|D_i| \leq U(D_i)$.**

Graphical representation of the results is given in Figure 2. In this case, if the uncertainty bar of a result crosses the X-axis, the uncertainty is considered confirmed.

$$CRV = (31.24 \pm 0.95)\ \mu Sv/nC\ (k=2)$$

$$U_{stab} = 0.075\ \mu Sv/nC\ (k=2)$$

Table 5: *Results of the comparison in N-40 radiation quality (all uncertainties are reported with k=2)*

Participant	N_H (µSv/nC)			$H^*(10)$ (mSv/h)	h_k (Sv/Gy)	D_i (%)	$U(D_i)$ (%)
PTB	31.24	±	0.95	6.00	1.20	0.00	0.24
IMBiH	31.32	±	1.40	7.06	1.20	0.26	5.41
PTB QC	31.29	±	0.95	6.00	1.20	0.17	0.24

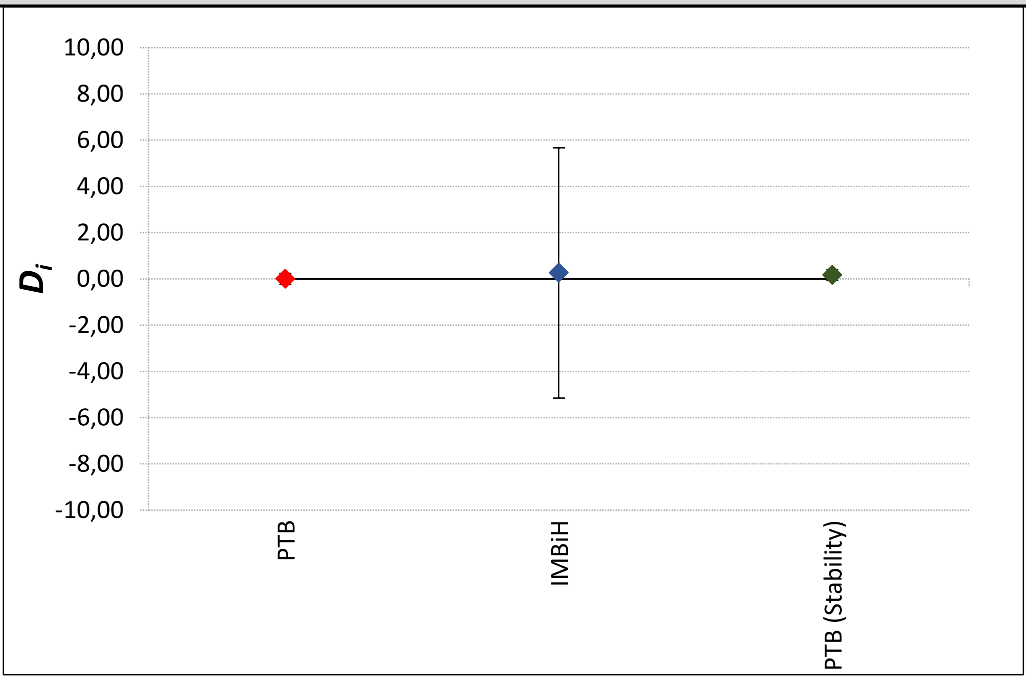

Figure 2: *Relative degrees of equivalence for radiation quality N-40*

The results of the comparison in radiation quality N-40 are consistent within the reported measurement uncertainty.

11. Results for radiation quality N-80

Results of the intercomparisons for N-80 radiation quality are presented in Table 6. All uncertainties in the table are expanded uncertainties, with coverage factor k = 2. For the purpose of this comparison, **it is considered that the uncertainty reported by the participant is confirmed if the following is true: $|D_i| \leq U(D_i)$.**

Graphical representation of the results is given in Figure 3. In this case, if the uncertainty bar of a result crosses the X-axis, the uncertainty is considered confirmed.

$$CRV = (35.87 \pm 1.09)\ \mu Sv/nC\ (k=2)$$

$$U_{stab} = 0.30\ \mu Sv/nC\ (k=2)$$

Table 6: *Results of the comparison in N-80 radiation quality (all uncertainties are reported with k=2)*

Participant	N_H (µSv/nC)			$H^*(10)$ (mSv/h)	h_k (Sv/Gy)	D_i (%)	$U(D_i)$ (%)
PTB	35.87	±	1.09	6.00	1.74	0.00	0.84
IMBiH	35.52	±	1.57	5.92	1.74	-0.99	5.39
PTB QC	36.08	±	1.10	6.00	1.74	0.60	0.91

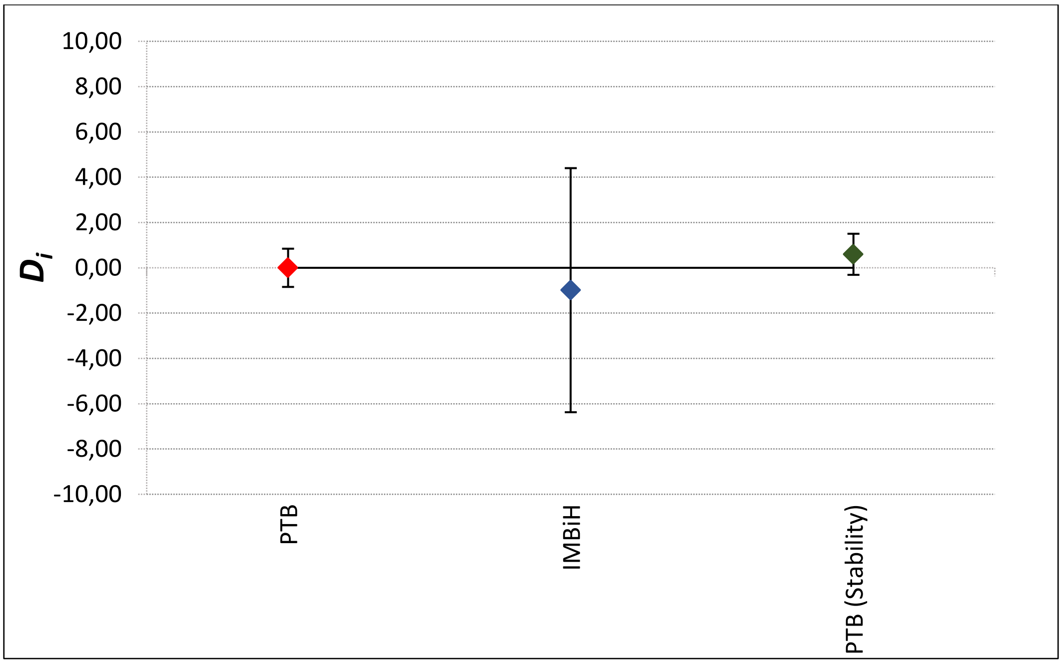

Figure 3: *Relative degrees of equivalence for radiation quality N-80*

The results of the comparison in radiation quality N-80 are consistent within the reported measurement uncertainty.

12. Results for radiation quality N-100

Results of the intercomparisons for N-100 radiation quality are presented in Table 7. All uncertainties in the table are expanded uncertainties, with coverage factor k = 2. For the purpose of this comparison, **it is considered that the uncertainty reported by the participant is confirmed if the following is true: $|D_i| \leq U(D_i)$.**

Graphical representation of the results is given in Figure 4. In this case, if the uncertainty bar of a result crosses the X-axis, the uncertainty is considered confirmed.

$$CRV = (35.00 \pm 1.06)\ \mu Sv/nC\ (k=2)$$

$$U_{stab} = 0.25\ \mu Sv/nC\ (k=2)$$

Table 7: *Results of the comparison in N-100 radiation quality (all uncertainties are reported with k=2)*

Participant	N_H (µSv/nC)			$H^*(10)$ (mSv/h)	h_k (Sv/Gy)	D_i (%)	$U(D_i)$ (%)
PTB	35.00	±	1.06	6.00	1.71	0.00	0.70
IMBiH	34.91	±	1.54	5.95	1.71	-0.25	5.39
PTB QC	35.18	±	1.07	6.00	1.71	0.50	0.77

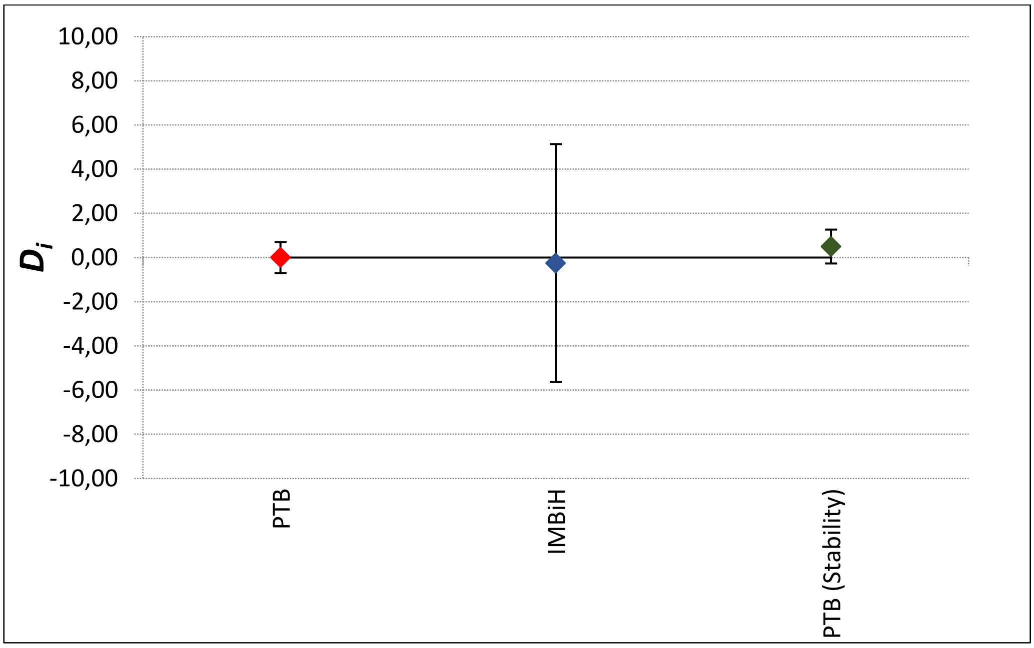

Figure 4: *Relative degrees of equivalence for radiation quality N-100*

The results of the comparison in radiation quality N-100 are consistent within the reported measurement uncertainty.

13. Results for radiation quality N-200

Results of the intercomparisons for N-200 radiation quality are presented in Table 8. All uncertainties in the table are expanded uncertainties, with coverage factor k = 2. For the purpose of this comparison, **it is considered that the uncertainty reported by the participant is confirmed if the following is true: $|D_i| \leq U(D_i)$.**

Graphical representation of the results is given in Figure 5. In this case, if the uncertainty bar of a result crosses the X-axis, the uncertainty is considered confirmed.

$$CRV = (34.01 \pm 1.03)\ \mu Sv/nC\ (k=2)$$

$$U_{stab} = 0.20\ \mu Sv/nC\ (k=2)$$

Table 8: *Results of the comparison in N-200 radiation quality (all uncertainties are reported with k=2)*

Participant	N_H (µSv/nC)			$H^*(10)$ (mSv/h)	h_k (Sv/Gy)	D_i (%)	$U(D_i)$ (%)
PTB	34.01	±	1.03	6.00	1.46	0.00	0.58
IMBiH	34.04	±	1.49	5.95	1.46	0.10	5.36
PTB QC	34.15	±	1.04	6.00	1.46	0.41	0.65

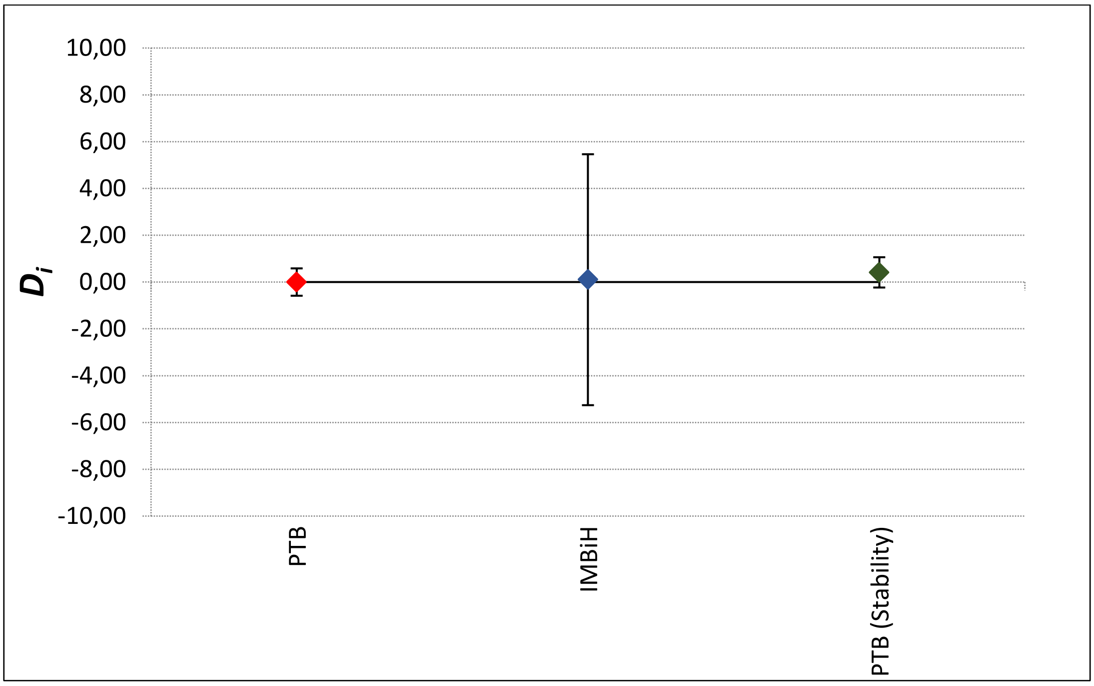

Figure 5: *Relative degrees of equivalence for radiation quality N-200*

The results of the comparison in radiation quality N-200 are consistent within the reported measurement uncertainty.

14. Results for radiation quality N-300

Results of the intercomparisons for N-300 radiation quality are presented in Table 9. All uncertainties in the table are expanded uncertainties, with coverage factor k = 2. For the purpose of this comparison, **it is considered that the uncertainty reported by the participant is confirmed if the following is true: $|D_i| \leq U(D_i)$.**

Graphical representation of the results is given in Figure 6. In this case, if the uncertainty bar of a result crosses the X-axis, the uncertainty is considered confirmed.

$$CRV = (33.20 \pm 1.01)\ \mu Sv/nC\ (k=2)$$

$$U_{stab} = 0.17\ \mu Sv/nC\ (k=2)$$

Table 9: *Results of the comparison in N-300 radiation quality (all uncertainties are reported with k=2)*

Participant	N_H (µSv/nC)			$H^*(10)$ (mSv/h)	h_k (Sv/Gy)	D_i (%)	$U(D_i)$ (%)
PTB	33.20	±	1.01	6.00	1.35	0.00	0.52
IMBiH	33.40	±	1.66	6.01	1.35	0.60	5.89
PTB QC	33.32	±	1.01	6.00	1.35	0.37	0.58

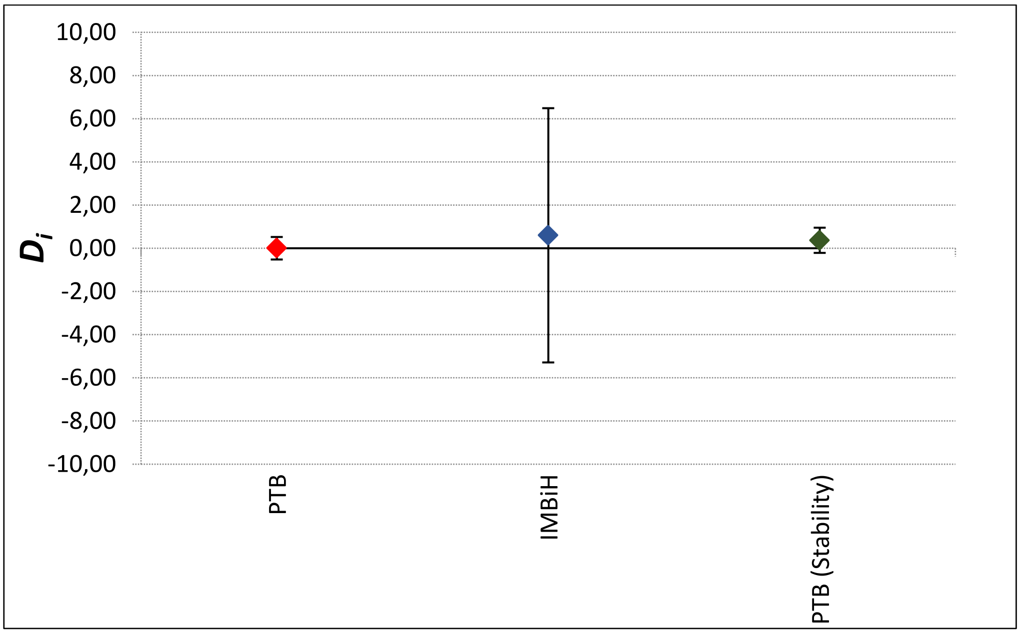

Figure 6: *Relative degrees of equivalence for radiation quality N-300*

The results of the comparison in radiation quality N-300 are consistent within the reported measurement uncertainty.

15. Results for radiation quality S-Cs

Results of the intercomparisons for S-Cs radiation quality are presented in Table 10. All uncertainties in the table are expanded uncertainties, with coverage factor k = 2. For the purpose of this comparison, **it is considered that the uncertainty reported by the participant is confirmed if the following is true: $|D_i| \leq U(D_i)$.**

Graphical representation of the results is given in Figure 7. In this case, if the uncertainty bar of a result crosses the X-axis, the uncertainty is considered confirmed.

$$CRV = (30.86 \pm 0.87)\ \mu Sv/nC\ (k=2)$$

$$U_{stab} = 0.17\ \mu Sv/nC\ (k=2)$$

Table 10: *Results of the comparison in S-Cs radiation quality (all uncertainties are reported with k=2)*

Participant	N_H (µSv/nC)			$H^*(10)$ (mSv/h)	h_k (Sv/Gy)	D_i (%)	$U(D_i)$ (%)
PTB	30.86	±	0.87	6.00	1.21	0.00	0.56
IMBiH	30.18	±	1.28	5.41	1.21	-2.21	5.06
PTB QC	30.84	±	0.87	6.00	1.21	-0.06	0.55

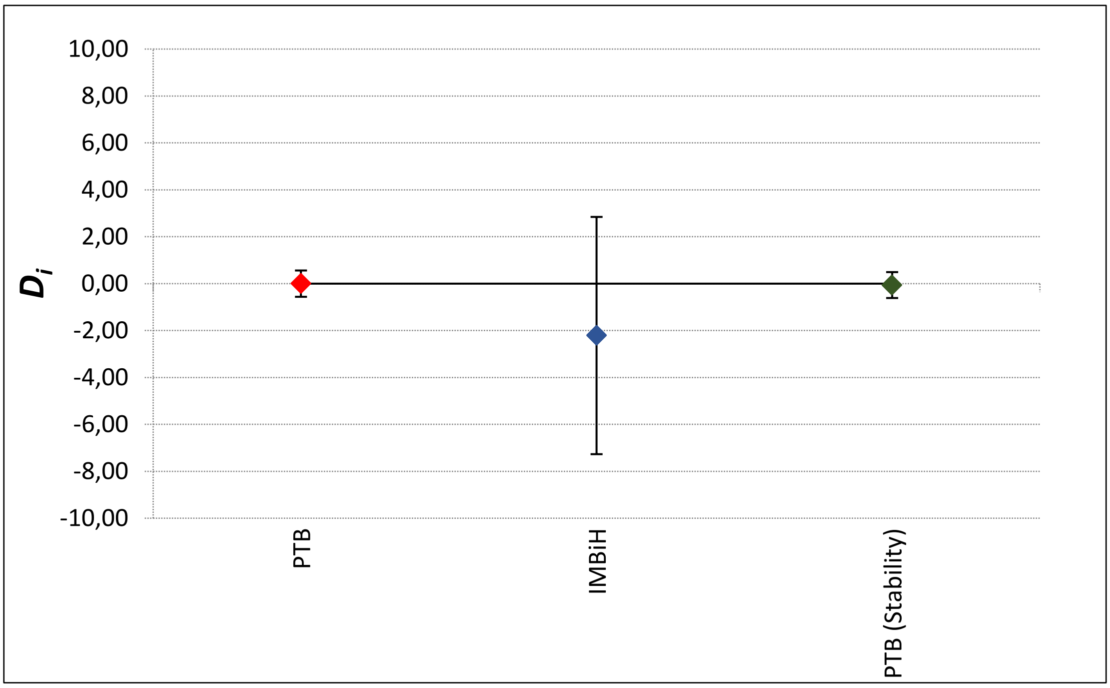

Figure 7: *Relative degrees of equivalence for radiation quality S-Cs*

The results of the comparison in radiation quality S-Cs are consistent within the reported measurement uncertainty.

16. Conclusion

EURAMET bilateral comparison of the H*(10) calibration coefficients for photon radiation was completed successfully. All the reported results are consistent within the reported uncertainties. The measurements were completed for the radiation qualities N-40, N-80, N-100, N-200, N-300 and S-Cs.
The transfer chamber stability was evaluated by performing measurements in PTB before and after measurements in IMBiH, and the uncertainty due to the stability was added to the uncertainty of the Degrees of Equivalence.

17. Acknowledgement

This comparison was performed as a part of the regional project entitled "Regional Consultancy Fund for Quality Infrastructure (QI) in South East Europe (SEE) " implemented by Physikalisch-Technische Bundesanstalt (PTB).

18. References

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19. Annex A: Measurement uncertainty budgets, as reported by participants

PTB

Radiation quality:	**N-40**
Focus-detector-distance FDD (cm):	250
Field diameter (cm):	40
$K_{a,ref}$ (mGy/h):	5.02
$H^*(10)_{ref}$ (mSv/h):	6.00
N_H (mSv/C) (comparison result):	**3.1238E+07**

Reference *H*10* determination				
All values are expressed as percentages				
Source of uncertainty	$u_{i,A}$	$u_{i,B}$	$u_{i,A}^2 + u_{i,B}^2$	**Comment**
Calibration coefficient of the national/reference standard		1.00%	0.0001	corrected for air density
Long term stability of reference standard			0	included in calibration coefficient
Nonlinearity of electrometer sensitivity			0	included in calibration coefficient
Change in source position			0	included in calibration coefficient
Radiation beam quality			0	included in calibration coefficient
Positioning reference instrument at a distance			0	included in calibration coefficient
Collected charge / ionization current (repeatability)		0.10%	0.000001	
Resolution			0	included in calibration coefficient
Leakage current			0	included in calibration coefficient
Air density correction			0	included in calibration coefficient
Temperature difference of the chamber			0	included in calibration coefficient
Pressure difference of the chamber			0	included in calibration coefficient
Conversion coefficient		1.00%	0.0001	

Other sources of uncertainty		0.54%	0.00002916	long term stability of monitor chamber and inhomogenity of radiation field
Combined uncertainty, *H*(10)*			0.00023016	
Transfer chamber measurements				
Source of uncertainty	$u_{i,A}$	$u_{i,B}$	$u_{i,A}^2 + u_{i,B}^2$	**Comment**
Homogeneity and field size			0	included in other sources above
Collected charge / ionization current (repeatability)	0.02%		0.00000004	corrected for air density
Resolution			0	included in calibration coefficient
Leakage current			0	included in calibration coefficient
Positioning transfer instrument at a distance			0	included in source to chamber distance
Air density correction			0	additional uncertainty negligible
Temperature difference of the chamber			0	negligible
Pressure difference of the chamber			0	negligible
Source to chamber distance		0.09%	0.00000081	
Other sources of uncertainty			0	
Combined uncertainty, *Q/I*			0.00000085	
Combined standard uncertainty, N_H	$u = \sqrt{\sum_i \left(u_{i,A}^2 + u_{i,B}^2\right)} =$		1.52%	

PTB

Radiation quality:	**N-80**
Focus-detector-distance FDD (cm):	250
Field diameter (cm):	40
$K_{a,ref}$ (mGy/h):	3.45
$H^*(10)_{ref}$ (mSv/h):	6.00
N_H (mSv/C) (comparison result):	**3.5870E+07**

Reference *H*10* determination				
All values are expressed as percentages				
Source of uncertainty	$u_{i,A}$	$u_{i,B}$	$u_{i,A}^2 + u_{i,B}^2$	**Comment**
Calibration coefficient of the national/reference standard		1.00%	0.0001	corrected for air density
Long term stability of reference standard			0	included in calibration coefficient
Nonlinearity of electrometer sensitivity			0	included in calibration coefficient
Change in source position			0	included in calibration coefficient
Radiation beam quality			0	included in calibration coefficient
Positioning reference instrument at a distance			0	included in calibration coefficient
Collected charge / ionization current (repeatability)		0.10%	0.000001	
Resolution			0	included in calibration coefficient
Leakage current			0	included in calibration coefficient
Air density correction			0	included in calibration coefficient
Temperature difference of the chamber			0	included in calibration coefficient
Pressure difference of the chamber			0	included in calibration coefficient
Conversion coefficient		1.00%	0.0001	
Other sources of uncertainty		0.54%	0.00002916	long term stability of monitor chamber and inhomogenity of radiation field

Combined uncertainty, *H*(10)*			0.00023016	
Transfer chamber measurements				
Source of uncertainty	$u_{i,A}$	$u_{i,B}$	$u_{i,A}^2 + u_{i,B}^2$	**Comment**
Homogeneity and field size			0	included in other sources above
Collected charge / ionization current (repeatability)	0.02%		0.00000004	corrected for air density
Resolution			0	included in calibration coefficient
Leakage current			0	included in calibration coefficient
Positioning transfer instrument at a distance			0	included in source to chamber distance
Air density correction			0	additional uncertainty negligible
Temperature difference of the chamber			0	negligible
Pressure difference of the chamber			0	negligible
Source to chamber distance		0.09%	0.00000081	
Other sources of uncertainty			0	
Combined uncertainty, *Q/I*			0.00000085	
Combined standard uncertainty, N_H	$u = \sqrt{\sum_i \left(u_{i,A}^2 + u_{i,B}^2\right)} =$		1.52%	

PTB

Radiation quality:	**N-100**
Focus-detector-distance FDD (cm):	250
Field diameter (cm):	40
$K_{a,ref}$ (mGy/h):	3.50
$H^*(10)_{ref}$ (mSv/h):	6.00
N_H (mSv/C) (comparison result):	**3.5002E+07**

Reference *H*10* determination				
All values are expressed as percentages				
Source of uncertainty	$u_{i,A}$	$u_{i,B}$	$u_{i,A}^2 + u_{i,B}^2$	**Comment**
Calibration coefficient of the national/reference standard		1.00%	0.0001	corrected for air density
Long term stability of reference standard			0	included in calibration coefficient
Nonlinearity of electrometer sensitivity			0	included in calibration coefficient
Change in source position			0	included in calibration coefficient
Radiation beam quality			0	included in calibration coefficient
Positioning reference instrument at a distance			0	included in calibration coefficient
Collected charge / ionization current (repeatability)		0.10%	0.000001	
Resolution			0	included in calibration coefficient
Leakage current			0	included in calibration coefficient
Air density correction			0	included in calibration coefficient
Temperature difference of the chamber			0	included in calibration coefficient
Pressure difference of the chamber			0	included in calibration coefficient
Conversion coefficient		1.00%	0.0001	
Other sources of uncertainty		0.54%	0.00002916	long term stability of monitor chamber and inhomogenity of radiation field

Combined uncertainty, *H*(10)*			0.00023016	
Transfer chamber measurements				
Source of uncertainty	$u_{i,\mathrm{A}}$	$u_{i,\mathrm{B}}$	$u_{i,\mathrm{A}}^2 + u_{i,\mathrm{B}}^2$	**Comment**
Homogeneity and field size			0	included in other sources above
Collected charge / ionization current (repeatability)	0.02%		0.00000004	corrected for air density
Resolution			0	included in calibration coefficient
Leakage current			0	included in calibration coefficient
Positioning transfer instrument at a distance			0	included in source to chamber distance
Air density correction			0	additional uncertainty negligible
Temperature difference of the chamber			0	negligible
Pressure difference of the chamber			0	negligible
Source to chamber distance		0.09%	0.00000081	
Other sources of uncertainty			0	
Combined uncertainty, *Q/I*			0.00000085	
Combined standard uncertainty, N_H	$u = \sqrt{\sum_i \left(u_{i,\mathrm{A}}^2 + u_{i,\mathrm{B}}^2\right)} =$		1.52%	

PTB

Radiation quality:	**N-200**
Focus-detector-distance FDD (cm):	250
Field diameter (cm):	40
$K_{a,ref}$ (mGy/h):	4.09
$H^*(10)_{ref}$ (mSv/h):	6.00
N_H (mSv/C) (comparison result):	**3.4006E+07**

Reference *H*10* determination				
All values are expressed as percentages				
Source of uncertainty	$u_{i,A}$	$u_{i,B}$	$u_{i,A}^2 + u_{i,B}^2$	**Comment**
Calibration coefficient of the national/reference standard		1.00%	0.0001	corrected for air density
Long term stability of reference standard			0	included in calibration coefficient
Nonlinearity of electrometer sensitivity			0	included in calibration coefficient
Change in source position			0	included in calibration coefficient
Radiation beam quality			0	included in calibration coefficient
Positioning reference instrument at a distance			0	included in calibration coefficient
Collected charge / ionization current (repeatability)		0.10%	0.000001	
Resolution			0	included in calibration coefficient
Leakage current			0	included in calibration coefficient
Air density correction			0	included in calibration coefficient
Temperature difference of the chamber			0	included in calibration coefficient
Pressure difference of the chamber			0	included in calibration coefficient
Conversion coefficient		1.00%	0.0001	
Other sources of uncertainty		0.54%	0.00002916	long term stability of monitor chamber and inhomogenity of radiation field

Combined uncertainty, *H*(10)*			0.00023016	
Transfer chamber measurements				
Source of uncertainty	$u_{i,\mathrm{A}}$	$u_{i,\mathrm{B}}$	$u_{i,\mathrm{A}}^2 + u_{i,\mathrm{B}}^2$	**Comment**
Homogeneity and field size			0	included in other sources above
Collected charge / ionization current (repeatability)	0.04%		0.00000016	corrected for air density
Resolution			0	included in calibration coefficient
Leakage current			0	included in calibration coefficient
Positioning transfer instrument at a distance			0	included in source to chamber distance
Air density correction			0	additional uncertainty negligible
Temperature difference of the chamber			0	negligible
Pressure difference of the chamber			0	negligible
Source to chamber distance		0.09%	0.00000081	
Other sources of uncertainty			0	
Combined uncertainty, *Q/I*			0.00000097	
Combined standard uncertainty, N_H	$u = \sqrt{\sum_i \left(u_{i,\mathrm{A}}^2 + u_{i,\mathrm{B}}^2\right)} =$		1.52%	

PTB

Radiation quality:	**N-300**
Focus-detector-distance FDD (cm):	250
Field diameter (cm):	40
$K_{a,ref}$ (mGy/h):	4.42
$H^*(10)_{ref}$ (mSv/h):	6.00
N_H (mSv/C) (comparison result):	**3.3201E+07**

Reference *H*10* determination				
All values are expressed as percentages				
Source of uncertainty	$u_{i,A}$	$u_{i,B}$	$u_{i,A}^2 + u_{i,B}^2$	**Comment**
Calibration coefficient of the national/reference standard		1.00%	0.0001	corrected for air density
Long term stability of reference standard			0	included in calibration coefficient
Nonlinearity of electrometer sensitivity			0	included in calibration coefficient
Change in source position			0	included in calibration coefficient
Radiation beam quality			0	included in calibration coefficient
Positioning reference instrument at a distance			0	included in calibration coefficient
Collected charge / ionization current (repeatability)		0.10%	0.000001	
Resolution			0	included in calibration coefficient
Leakage current			0	included in calibration coefficient
Air density correction			0	included in calibration coefficient
Temperature difference of the chamber			0	included in calibration coefficient
Pressure difference of the chamber			0	included in calibration coefficient
Conversion coefficient		1.00%	0.0001	
Other sources of uncertainty		0.54%	0.00002916	long term stability of monitor chamber and inhomogenity of radiation field

Combined uncertainty, *H*(10)*			0.00023016	
Transfer chamber measurements				
Source of uncertainty	$u_{i,A}$	$u_{i,B}$	$u_{i,A}^2 + u_{i,B}^2$	**Comment**
Homogeneity and field size			0	included in other sources above
Collected charge / ionization current (repeatability)	0.03%		0.00000009	corrected for air density
Resolution			0	included in calibration coefficient
Leakage current			0	included in calibration coefficient
Positioning transfer instrument at a distance			0	included in source to chamber distance
Air density correction			0	additional uncertainty negligible
Temperature difference of the chamber			0	negligible
Pressure difference of the chamber			0	negligible
Source to chamber distance		0.09%	0.00000081	
Other sources of uncertainty			0	
Combined uncertainty, *Q/I*			0.0000009	
Combined standard uncertainty, N_H	$u = \sqrt{\sum_i \left(u_{i,A}^2 + u_{i,B}^2\right)} =$		1.52%	

PTB

Radiation quality:	S-Cs
Focus-detector-distance FDD (cm):	270,4
Field diameter (cm):	57
$K_{a,ref}$ (mGy/h):	4,92
$H^*(10)_{ref}$ (mSv/h):	6,00
N_H (mSv/C) (comparison result):	3,0863E+07

Reference *H*10* determination				
All values are expressed as percentages				
Source of uncertainty	$u_{i,A}$	$u_{i,B}$	$u_{i,A}^2 + u_{i,B}^2$	Comment
Calibration coefficient of the national/reference standard		0,84%	0,00007056	
Long term stability of reference standard			0	included in calibration coefficient
Nonlinearity of electrometer sensitivity			0	included in calibration coefficient
Change in source position			0	included in calibration coefficient
Radiation beam quality			0	included in calibration coefficient
Positioning reference instrument at a distance			0	included in calibration coefficient
Collected charge / ionization current (repeatability)			0	included in calibration coefficient
Resolution			0	included in calibration coefficient
Leakage current			0	included in calibration coefficient
Air density correction			0	included in calibration coefficient
Temperature difference of the chamber			0	included in calibration coefficient
Pressure difference of the chamber			0	included in calibration coefficient
Conversion coefficient		1,00%	0,0001	

Other sources of uncertainty			0	
Combined uncertainty, *H*(10)*			0,00017056	
Transfer chamber measurements				
Source of uncertainty	$u_{i,A}$	$u_{i,B}$	$u_{i,A}^2 + u_{i,B}^2$	Comment
Homogeneity and field size			0	included in other sources
Collected charge / ionization current (repeatability)	0,03%		0,00000009	
Resolution			0	negligible
Leakage current			0	negligible
Positioning transfer instrument at a distance			0	included in other sources
Air density correction		0,01%	0,00000001	
Temperature difference of the chamber			0	not relevant
Pressure difference of the chamber			0	not relevant
Source to chamber distance		0,09%	0,00000081	
Other sources of uncertainty		0,54%	0,00002916	Reproducebility of source position and inhomogenity of radiation field
Combined uncertainty, *Q/I*			0,00003007	
Combined standard uncertainty, N_H	$u = \sqrt{\sum_i \left(u_{i,A}^2 + u_{i,B}^2\right)} =$		1,42%	

IMBiH

Radiation quality:	**N-40**
Focus-detector-distance FDD (cm):	200
Field diameter (cm):	32.03
$K_{a,ref}$ (mGy/h):	4.87
$H^*(10)_{ref}$ (mSv/h):	5.84
N_H (µSv/nC) (comparison result):	**31.32**

Reference *H*10* determination				
All values are expressed as percentages				
Source of uncertainty	$u_{i,A}$	$u_{i,B}$	$u_{i,A}^2 + u_{i,B}^2$	**Comment**
Calibration coefficient of the national/reference standard		0.71	0.5041	
Stability of reference chamber + electrometer	0.26		0.0676	
Nonlinearity of electrometer sensitivity		0.14	0.0196	
Radiation field and source				
Radiation beam quality		0.43	0.1849	
Homogenity and field size		0.14	0.0196	
Measurements with reference instrument				
Positioning reference instrument at a distance		0.22	0.0484	
Repeatability	0.00		0.0000	
Resolution		0.00	0.0000	
Leakage current		0.00	0.0000	
Ambient conditions				
Air density correction		0.17	0.0289	
Temperature difference of the chamber		0.00	0.0000	
Pressure difference of the chamber		0.00	0.0000	
Conversion coefficient		2.00	4.0000	
Combined uncertainty, *H*(10)*			**4.8731**	
Transfer chamber measurements				
Source of uncertainty	$u_{i,A}$	$u_{i,B}$	$u_{i,A}^2 + u_{i,B}^2$	**Comment**
Radiation field and source				
Homogenity and field		0.14	0.0196	

size				
Measurements with transfer instrument				
Positioning transfer instrument at a distance		0.22	0.0484	
Repeatability	0.00		0.0000	
Resolution		0.00	0.0000	
Leakage current		0.00	0.0000	
Ambient conditions				
Air density correction	0.00	0.17	00289	
Temperature difference of the chamber		0.00	0.0000	
Pressure difference of the chamber		0.00	0.0000	
Combined uncertainty,*Q/I*			0.0969	
Combined standard uncertainty, N_H	$u = \sqrt{\sum_i \left(u_{i,A}^2 + u_{i,B}^2\right)} =$		**2.23**	

IMBiH

Radiation quality:	**N-80**
Focus-detector-distance FDD (cm):	200
Field diameter (cm):	32.03
$K_{a,ref}$ (mGy/h):	3.40
$H^*(10)_{ref}$ (mSv/h):	5.92
N_H (µSv/nC) (comparison result):	**35.52**

Reference *H*10* determination				
All values are expressed as percentages				
Source of uncertainty	$u_{i,A}$	$u_{i,B}$	$u_{i,A}^2 + u_{i,B}^2$	**Comment**
Calibration coefficient of the national/reference standard		0.69	0.4761	
Stability of reference chamber + electrometer	0.26		0.0676	
Nonlinearity of electrometer sensitivity		0.14	0.0196	
Radiation field and source				
Radiation beam quality		0.33	0.1089	
Homogenity and field size		0.14	0.0196	
Measurements with reference instrument				
Positioning reference instrument at a distance		0.22	0.0484	
Repeatability	0.00		0.0000	
Resolution		0.00	0.0000	
Leakage current		0.00	0.0000	
Ambient conditions				
Air density correction	0.00	0.17	0.0289	
Temperature difference of the chamber		0.00	0.0000	
Pressure difference of the chamber		0.00	0.0000	
Conversion coefficient		2.00	4.0000	
Combined uncertainty, *H*(10)*			**4.7691**	
Transfer chamber measurements				
Source of uncertainty	$u_{i,A}$	$u_{i,B}$	$u_{i,A}^2 + u_{i,B}^2$	**Comment**

Radiation field and source				
Homogenity and field size		0.14	0.0196	
Measurements with transfer instrument				
Positioning transfer instrument at a distance		0.22	0.0484	
Repeatability	0.00		0.0000	
Resolution		0.00	0.0000	
Leakage current		0.00	0.0000	
Ambient conditions				
Air density correction	0.00	0.17	0.0289	
Temperature difference of the chamber		0.00	0.0000	
Pressure difference of the chamber		0.00	0.0000	
Combined uncertainty,*Q/I*			0.0969	
Combined standard uncertainty, N_H	$u = \sqrt{\sum_i \left(u_{i,\mathrm{A}}^2 + u_{i,\mathrm{B}}^2\right)} =$		**2.21**	

IMBiH

Radiation quality:	**N-100**
Focus-detector-distance FDD (cm):	200
Field diameter (cm):	32.03
$K_{a,ref}$ (mGy/h):	3.48
$H^*(10)_{ref}$ (mSv/h):	5.95
N_H (µSv/nC) (comparison result):	**34.91**

Reference *H*10* determination				
All values are expressed as percentages				
Source of uncertainty	$u_{i,A}$	$u_{i,B}$	$u_{i,A}^2 + u_{i,B}^2$	**Comment**
Calibration coefficient of the national/reference standard		0.71	0.5041	
Stability of reference chamber + electrometer	0.26		0.0676	
Nonlinearity of electrometer sensitivity		0.14	0.0196	
Radiation field and source				
Radiation beam quality		0.24	0.0576	
Homogenity and field size		0.14	0.0196	
Measurements with reference instrument				
Positioning reference instrument at a distance		0.22	0.0484	
Repeatability	0.00		0.0000	
Resolution		0.00	0.0000	
Leakage current		0.00	0.0000	
Ambient conditions				
Air density correction	0.00	0.17	0.0289	
Temperature difference of the chamber		0.00	0.0000	
Pressure difference of the chamber		0.00	0.0000	
Conversion coefficient		2.00	4.0000	
Combined uncertainty, *H*(10)*			**4.7458**	
Transfer chamber measurements				
Source of uncertainty	$u_{i,A}$	$u_{i,B}$	$u_{i,A}^2 + u_{i,B}^2$	**Comment**
Radiation field and source				
Homogenity and field size		0.14	0.0196	

Measurements with transfer instrument				
Positioning transfer instrument at a distance		0.22	0.0484	
Repeatability	0.00		0.0000	
Resolution		0.00	0.0000	
Leakage current		0.00	0.0000	
Ambient conditions				
Air density correction	0.00	0.17	0.0289	
Temperature difference of the chamber		0.00	0.0000	
Pressure difference of the chamber		0.00	0.0000	
Combined uncertainty,*Q/I*			0.0969	
Combined standard uncertainty, N_H	$u = \sqrt{\sum_i \left(u_{i,A}^2 + u_{i,B}^2\right)} =$		**2.20**	

IMBiH

Radiation quality:	**N-200**
Focus-detector-distance FDD (cm):	200
Field diameter (cm):	32.03
$K_{a,ref}$ (mGy/h):	4.12
$H^*(10)_{ref}$ (mSv/h):	6.01
N_H (µSv/nC) (comparison result):	**34.04**

Reference *H*10* determination				
All values are expressed as percentages				
Source of uncertainty	$u_{i,A}$	$u_{i,B}$	$u_{i,A}^2 + u_{i,B}^2$	**Comment**
Calibration coefficient of the national/reference standard		0.69	0.4761	
Stability of reference chamber + electrometer	0.26		0.0676	
Nonlinearity of electrometer sensitivity		0.14	0.0196	
Radiation field and source				
Radiation beam quality		0.15	0.0225	
Homogenity and field size		0.14	0.0196	
Measurements with reference instrument				
Positioning reference instrument at a distance		0.22	0.0484	
Repeatability	0.00		0.0000	
Resolution		0.00	0.0000	
Leakage current		0.00	0.0000	
Ambient conditions				
Air density correction	0.00	0.17	0.0289	
Temperature difference of the chamber		0.00	0.0000	
Pressure difference of the chamber		0.00	0.0000	
Conversion coefficient		2.00	4.0000	
Combined uncertainty, *H*(10)*			**4.6827**	
Transfer chamber measurements				
Source of uncertainty	$u_{i,A}$	$u_{i,B}$	$u_{i,A}^2 + u_{i,B}^2$	**Comment**
Radiation field and source				
Homogenity and field size		0.14	0.0196	

Measurements with transfer instrument				
Positioning transfer instrument at a distance		0.22	0.0484	
Repeatability	0.00		0.0000	
Resolution		0.00	0.0000	
Leakage current		0.00	0.0000	
Ambient conditions				
Air density correction	0.00	0.17	0.0289	
Temperature difference of the chamber		0.00	0.0000	
Pressure difference of the chamber		0.00	0.0000	
Combined uncertainty,*Q/I*			0.0969	
Combined standard uncertainty, N_H	$u = \sqrt{\sum_i \left(u_{i,A}^2 + u_{i,B}^2\right)} =$		**2.19**	

IMBiH

Radiation quality:	**N-300**
Focus-detector-distance FDD (cm):	200
Field diameter (cm):	32.03
$K_{a,ref}$ (mGy/h):	4.41
$H^*(10)_{ref}$ (mSv/h):	5.95
N_H (µSv/nC) (comparison result):	**33.40**

Reference *H*10* determination				
All values are expressed as percentages				
Source of uncertainty	$u_{i,A}$	$u_{i,B}$	$u_{i,A}^2 + u_{i,B}^2$	**Comment**
Calibration coefficient of the national/reference standard		0.70	0.4900	
Stability of reference chamber + electrometer	0.26		0.0676	
Nonlinearity of electrometer sensitivity		0.14	0.0196	
Radiation field and source				
Radiation beam quality		1.20	1.4400	
Homogenity and field size		0.14	0.0196	
Measurements with reference instrument				
Positioning reference instrument at a distance		0.22	0.0484	
Repeatability	0.00		0.0000	
Resolution		0.00	0.0000	
Leakage current		0.00	0.0000	
Ambient conditions				
Air density correction	0.00	0.17	0.0289	
Temperature difference of the chamber		0.00	0.0000	
Pressure difference of the chamber		0.00	0.0000	
Conversion coefficient		2.00	4.0000	
Combined uncertainty, *H*(10)*			**6.1141**	
Transfer chamber measurements				
Source of uncertainty	$u_{i,A}$	$u_{i,B}$	$u_{i,A}^2 + u_{i,B}^2$	**Comment**
Radiation field and source				
Homogenity and field size		0.14	0.0196	

Measurements with transfer instrument				
Positioning transfer instrument at a distance		0.22	0.0484	
Repeatability	0.00		0.0000	
Resolution		0.00	0.0000	
Leakage current		0.00	0.0000	
Ambient conditions				
Air density correction	0.00	0.17	0.0289	
Temperature difference of the chamber		0.00	0.0000	
Pressure difference of the chamber		0.00	0.0000	
Combined uncertainty,*Q/I*			0.0969	
Combined standard uncertainty, N_H	$u = \sqrt{\sum_i \left(u_{i,A}^2 + u_{i,B}^2\right)} =$		**2.49**	

IMBiH

Radiation quality:	**S-Cs**
Focus-detector-distance FDD (cm):	300
Field diameter (cm):	58.16
$K_{a,ref}$ (mGy/h):	4.47
$H*(10)_{ref}$ (mSv/h):	5.41
N_H (µSv/nC) (comparison result):	**30.18**

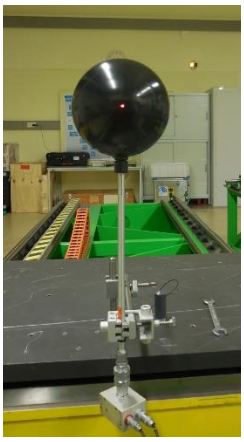
Reference *H*10* determination				
All values are expressed as percentages				
Source of uncertainty	$u_{i,A}$	$u_{i,B}$	$u_{i,A}^2 + u_{i,B}^2$	**Comment**
Calibration coefficient of the national/reference standard		0.41	0.1681	
Calibration coefficient of the reference electrometer		0.08	0.0069	
Stability of reference chamber + electrometer	0.27		0.0729	
Nonlinearity of electrometer sensitivity		0.14	0.0196	
Radiation field and source				
Change in source position		0.17	0.0289	
Radiation beam quality		0.10	0.0100	
Homogenity and field size		0.00	0.0000	
Measurements with reference instrument				
Positioning reference instrument at a distance		0.26	0.0676	
Repeatability	0.00		0.0000	
Resolution		0.00	0.0000	
Leakage current		0.00	0.0000	
Ambient conditions				
Air density correction	0.00	0.17	0.0289	
Temperature difference of the chamber		0.00	0.0000	
Pressure difference of the chamber		0.00	0.0000	
Conversion coefficient		2.00	4.0000	
Combined uncertainty, *H*(10)*			**4.4029**	
Transfer chamber measurements				

Source of uncertainty	$u_{i,A}$	$u_{i,B}$	$u_{i,A}^2 + u_{i,B}^2$	Comment
Radiation field and source				
Homogenity and field size		0.00	0.0000	
Measurements with transfer instrument				
Positioning transfer instrument at a distance		0.27	0.0729	
Repeatability	0.00		0.0000	
Resolution		0.00	0.0000	
Leakage current		0.00	0.0000	
Ambient conditions				
Air density correction	0.00	0.17	0.0289	
Temperature difference of the chamber		0.00	0.0000	
Pressure difference of the chamber		0.00	0.0000	
Combined uncertainty, ***Q/I***			0.1018	
Combined standard uncertainty, N_H	$u = \sqrt{\sum_i \left(u_{i,A}^2 + u_{i,B}^2\right)} =$		**2.12**	

20. Annex B: Measurement conditions and setup

PTB

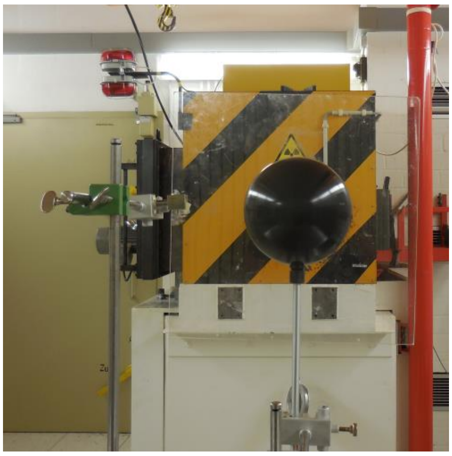
Calibration date/period:	**6.10.2021**
Radiation quality:	N-40 to N-300
Method of determination of H*(10):	The procedure for determining the conventional quantity value of $H^*(10)$ was performed according to the international standard ISO 4037:3 2019 by using conversion coefficients $h^*_K(10;U)$ from air kerma free-in-air K_a to ambient dose equivalent, $H^*(10)$ for the radiation quality U: $\dot{H}^*(10)=h^*_K(10;U)*\dot{K}_a$, The conventional quantity value of air kerma rate is traceable to the PTB primary standard laboratory for air kerma free-in-air. For the generated X-ray field, a high stable ionization chamber (PTW, Type No. M23361, volume: 30 cm^3,) was calibrated against the K_a – primary standard chambers for X-radiation. By means of this chamber the conventional quantity value of the air kerma free-in-air, K_a, is transferred to the monitor chamber of the X-ray facility used. The monitor chamber coefficient N_{MK} (quotient between K_a and the chamber charge measured) is determined for each radiation quality and at each point of test. The quotient between K_a and the measured irradiation time is then the conventional quantity value of $\dot{K}_a$. At the X-ray facility, the conversion coefficient from K_a to $H^*(10)$ at the point of test was determined by means of X-ray spectrometry. A detailed description of the X-ray spectrometry including information about the spectrometer and the electronic devices used and a detailed description of the determination of the conversion coefficients are given in [Ankerhold, U., Catalogue of X-ray spectra and their characteristic data – ISO and DIN radiation qualities, therapy and diagnostic radiation qualities, unfiltered X-ray spectra –, PTB-Report, PTB-Dos-34, 119 p., April 2000, ISBN 3-89701-513-7]. There, a detailed analysis of the uncertainty is given, too.
Conversion factor value and source (if applicable):	The conversion coefficient is determined by spectrometry with a HPGe spectrometer and using an unfolding procedure. N-40: 1.20 N-80: 1.74 N-100: 1.71 N-200: 1.46 N-300: 1.35

Description of the equipment used for calibration:	The charge measurements were done with a PTB-developed electrometer [G. Buchholz, Ladungsmesser, PTB-Report, PTB-EW-12, July 2004, ISBN 3-86509-158-X] and have been repeated at least 6 times. The resulting current has been corrected for leakage current and for environmental conditions (temperature and pressure).
Description of calibration setup:	Calibration was done by using a traceable calibrated monitor transmission ionisation camber.
Picture of the calibration setup: 	
Determination of calibration coefficients (list all used corrections):	At the X-ray equipment, parallel to the current measurement of the transfer chamber the air kerma rate was determined by the monitor chamber. Multiplication with the conversion coefficient gives the conventional quantity value of the ambient dose equivalent rate, $\dot{H}^*$ (10): $\dot{H}^*(10) = h^*_K (10;U)\cdot\dot{K}_a$ with $\dot{K}a = N_{MK} \cdot I_{MK} \cdot k_\rho$ I_{MK} is the current measured by the monitor chamber, N_{MK} is the monitor chamber coefficient (see section 4.1). k_ρ is the correction factor for considering the environmental influences (temperature and pressure). As the results of the calibration measurements the calibration coefficient in Sv/C is given at each radiation quality by: $N_H=(\dot{H}^*(10))/I$
Calibration was performed by:	Christian Fuhg

PTB

Calibration date/period:	**06.10.2021**
Radiation quality:	S-Cs
Method of determination of H*(10):	See N-40 + For the irradiations at the gamma radiation facility, the doserate of the sources were determined in advance by measurements with the primary standard chambers. In cases where the doserate were too low to measure with the primary standard chambers, a secondary standard chamber with larger volume was used. This secondary standard chamber has been calibrated against the primary standard at higher doserates. At the gamma radiation facility, the conversion coefficient from ISO 4037-3:2019 was used.
Conversion factor value and source (if applicable):	1.21 ISO 4037-3:2019
Description of the equipment used for calibration:	The charge measurements were done with a traceable-calibrated electrometer and have been repeated at least 6 times. The resulting current has been corrected for leakage current and for environmental conditions (temperature and pressure).
Description of calibration setup:	Calibration was done by using a built-up plate according to ISO 4037-3:2019.

Picture of the calibration setup:

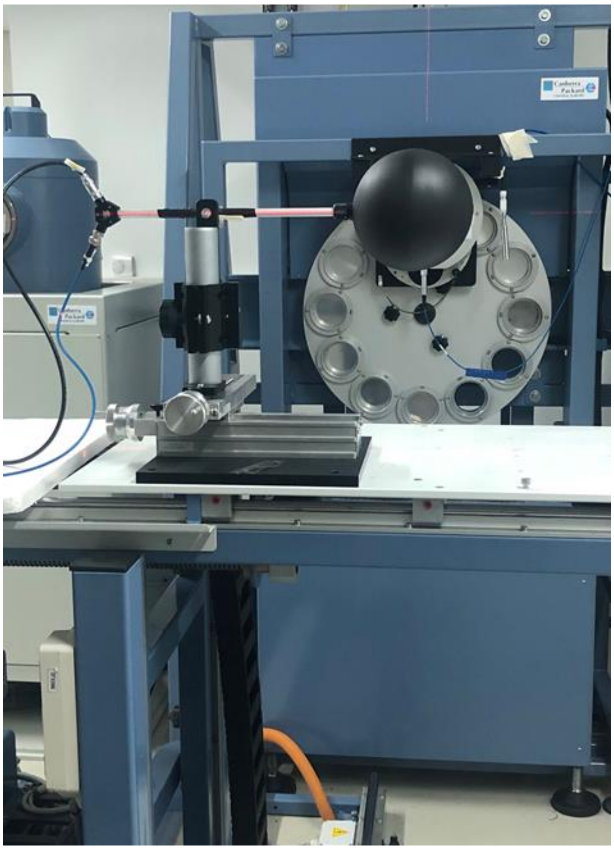


Determination of calibration coefficients (list all used corrections):	At the gamma radiation facility conventional quantity value of the ambient dose equivalent rate, $\dot{H}^*(10)$ was determined by multiplication of the air kerma rate $\dot{K}_a$ and the conversion coefficient : $\dot{H}^*(10) = h^*_K(10;U) \cdot \dot{K}_a$ As the results of the calibration measurements the calibration coefficient in Sv/C is given at each radiation quality by: $N_H = (\dot{H}^*(10))/I$
Calibration was performed by:	Christian Fuhg

IMBiH

Calibration date/period:	**29.12.2021 - 4.01.2022**
Radiation quality:	N-40
Method of determination of H*(10):	Reference instrument is calibrated in terms of air kerma (Ka) by method of substitution, and conversion coefficient from Ka to H*(10) is used. The value of H*(10) was determined according to the standard BAS ISO 4037-3:2019 by using conversion coefficients $h^*_K(10;N)$ from air kerma free-in-air, Ka, to ambient dose equivalent, H*(10), for the radiation quality N: $\dot{H}^*(10)=\dot{K}a*h^*_K(10;N)$
Conversion factor value and source (if applicable):	Conversion coefficient from Ka to H*(10), h^*_K= 1.20 (based on interpolation of conversion coeffiecient for distance of 2.0 m, according to BAS ISO 4037-3:2019
Description of the equipment used for calibration:	The calibrations of the transfer chamber were performed against the IMBiH reference secondary-standard chamber, type PTW32002 s.n. 478, calibrated at the IAEA 27.09.2021. The distance between the focus and reference point of the chamber was 200 cm and the field size diameter 32.03 cm. HVL determined at the laboratory is 2.79 mm Al. Ionization currents were measured using PTW UNIDOS Webline electrometer Type T10022 s.n. 298 based on charge measurement. Electrometer was calibrated in 2021 at the IAEA as a system consisting of reference ionization chamber and electrometer. No monitor chamber was used.
Description of calibration setup:	The IMBiH SSDL laboratory houses a high-stability generator and a bipolar tungsten-anode X RAY tube of type MXR-321, with a 3 mm beryllium window. Transfer chamber is oriented in such way that the Type and S/N are pointed towards the radiation source.

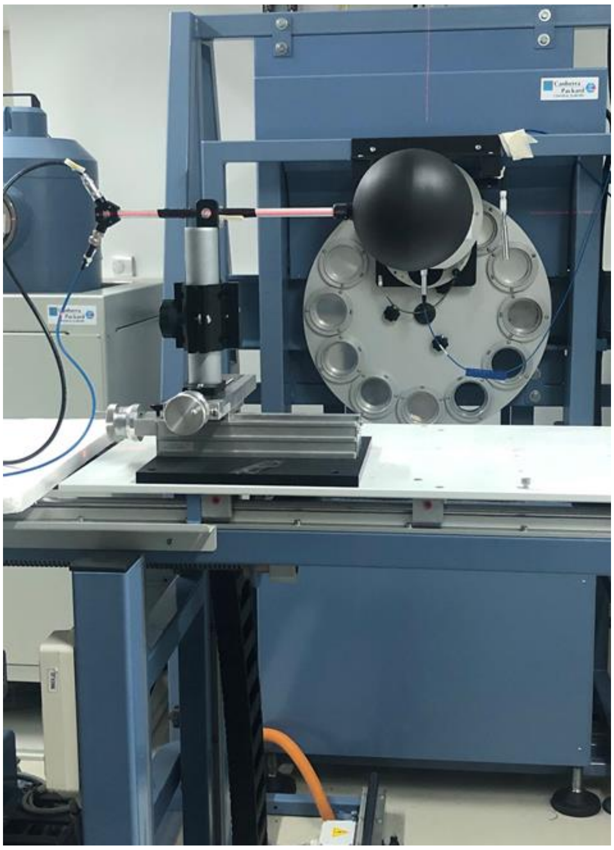
Picture of the calibration setup:



Determination of calibration coefficients (list all used corrections):	Basic formula that was used with all corrections, and description of the corrections, for example: $$N_H = \frac{Q_{ref} * N_{Ka} * k_{d,ref} * h_k}{Q_{user} * k_{d,user} * k_{elec}}$$ where ref and user denote reference measurements and measurements with transfer chamber, k_d is correction for air density, h_k conversion coefficient from air kerma to H*(10), kelec is electrometer calibration factor. The Q_{ref} and Q_{user} are corrected to the standard conditions of air temperature, pressure and relative humidity chosen for the comparison (T = 293.15 K, P = 101.325 kPa and h = 50%)
Calibration was performed by:	Amra Sabeta and Vedrana Makaric

IMBiH

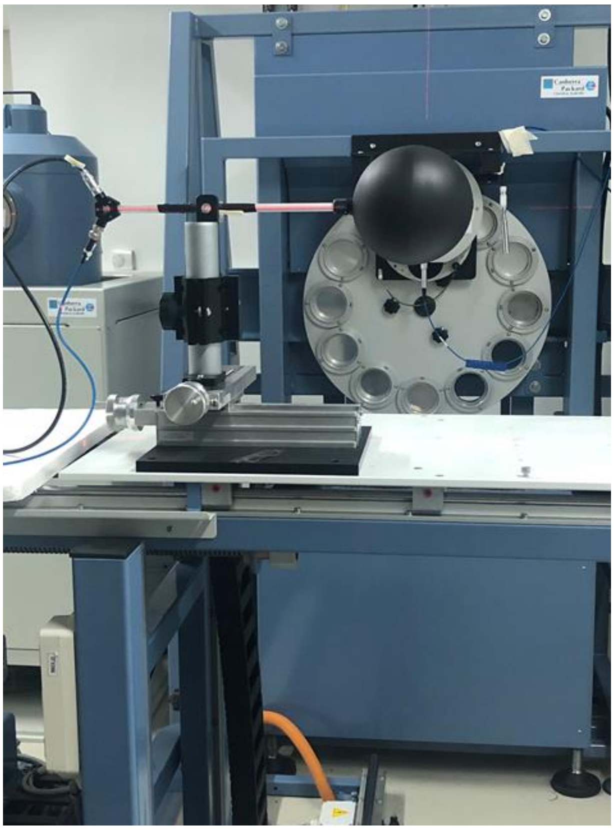
Calibration date/period:	**29.12.2021 - 4.01.2022**
Radiation quality:	N-80
Method of determination of H*(10):	Reference instrument is calibrated in terms of air kerma (Ka) by method of substitution, and conversion coefficient from Ka to H*(10) is used. The value of H*(10) was determined according to the standard BAS ISO 4037-3:2019 by using conversion coefficients $h^*_K(10;N)$ from air kerma free-in-air, Ka, to ambient dose equivalent, H*(10), for the radiation quality N: $\dot{H}^*(10)=\dot{K}a*h^*_K(10;N)$
Conversion factor value and source (if applicable):	Conversion coefficient from Air kerma to H*(10), h^*_K= 1.74 (according to BAS ISO 4037-3:2019)
Description of the equipment used for calibration:	The calibrations of the transfer chamber were performed against the IMBiH reference secondary-standard chamber, type PTW32002 s.n. 478, calibrated at the IAEA 27.09.2021. The distance between the focus and reference point of the chamber was 200 cm and the field size diameter 32.03 cm. HVL determined at the laboratory is 0.64 mm Cu. Ionization currents were measured using PTW UNIDOS Webline electrometer Type T10022 s.n. 298 based on charge measurement. Electrometer was calibrated in 2021 at the IAEA as a system consisting of reference ionization chamber and electrometer. No monitor chamber was used.
Description of calibration setup:	The IMBiH SSDL laboratory houses a high-stability generator and a bipolar tungsten-anode X RAY tube of type MXR-321, with a 3 mm beryllium window. Transfer chamber is oriented in such way that the Type and S/N are pointed towards the radiation source.

<table>
<tr><td colspan="2">Picture of the calibration setup:
</td></tr>
<tr><td>Determination of calibration coefficients (list all used corrections):</td><td>Basic formula that was used with all corrections, and description of the corrections, for example:
$$N_H = \frac{Q_{ref} * N_{Ka} * k_{d,ref} * h_k}{Q_{user} * k_{d,user} * k_{elec}}$$
where ref and user denote reference measurements and measurements with transfer chamber, k_d is correction for air density, h_k conversion coefficient from air kerma to H*(10), kelec is electrometer calibration factor.

The Q_{ref} and Q_{user} are corrected to the standard conditions of air temperature, pressure and relative humidity chosen for the comparison (T = 293.15 K, P = 101.325 kPa and h = 50%)</td></tr>
<tr><td>Calibration was performed by:</td><td>Amra Sabeta and Vedrana Makaric</td></tr>
</table>

IMBiH

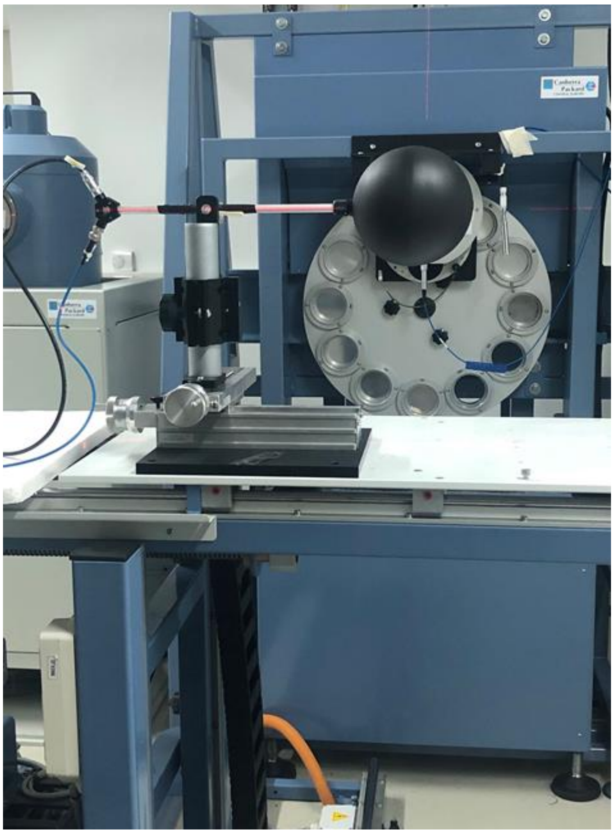
Calibration date/period:	**29.12.2021 - 4.01.2022**
Radiation quality:	N-100
Method of determination of H*(10):	Reference instrument is calibrated in terms of air kerma (Ka) by method of substitution, and conversion coefficient from Ka to H*(10) is used. The value of H*(10) was determined according to the standard BAS ISO 4037-3:2019 by using conversion coefficients $h^*_K(10;N)$ from air kerma free-in-air, Ka, to ambient dose equivalent, H*(10), for the radiation quality N: $\dot{H}^*(10)=\dot{K}a * h^*_K(10;N)$
Conversion factor value and source (if applicable):	Conversion coefficient from Air kerma to H*(10), h^*_K= 1.71 (according to BAS ISO 4037-3:2019)
Description of the equipment used for calibration:	The calibrations of the transfer chamber were performed against the IMBiH reference secondary-standard chamber, type PTW32002 s.n. 478, calibrated at the IAEA 27.09.2021. The distance between the focus and reference point of the chamber was 200 cm and the field size diameter 32.03 cm. HVL determined at the laboratory is 1.18 mm Cu. Ionization currents were measured using PTW UNIDOS Webline electrometer Type T10022 s.n. 298 based on charge measurement. Electrometer was calibrated in 2021 at the IAEA as a system consisting of reference ionization chamber and electrometer. No monitor chamber was used.
Description of calibration setup:	The IMBiH SSDL laboratory houses a high-stability generator and a bipolar tungsten-anode X RAY tube of type MXR-321, with a 3 mm beryllium window. Transfer chamber is oriented in such way that the Type and S/N are pointed towards the radiation source.

Picture of the calibration setup:	
	
Determination of calibration coefficients (list all used corrections):	Basic formula that was used with all corrections, and description of the corrections, for example: $$N_H = \frac{Q_{ref} * N_{Ka} * k_{d,ref} * h_k}{Q_{user} * k_{d,user} * k_{elec}}$$ where ref and user denote reference measurements and measurements with transfer chamber, k_d is correction for air density, h_k conversion coefficient from air kerma to H*(10), kelec is electrometer calibration factor. The Q_{ref} and Q_{user} are corrected to the standard conditions of air temperature, pressure and relative humidity chosen for the comparison (T = 293.15 K, P = 101.325 kPa and h = 50%)
Calibration was performed by:	Amra Sabeta and Vedrana Makaric

IMBiH

Calibration date/period:	**29.12.2021 - 4.01.2022**
Radiation quality:	N-200
Method of determination of H*(10):	Reference instrument is calibrated in terms of air kerma (Ka) by method of substitution, and conversion coefficient from Ka to H*(10) is used. The value of H*(10) was determined according to the standard BAS ISO 4037-3:2019 by using conversion coefficients $h^*_K(10;N)$ from air kerma free-in-air, Ka, to ambient dose equivalent, H*(10), for the radiation quality N: $\dot{H}^*(10)=\dot{K}a^*h^*_K(10;N)$
Conversion factor value and source (if applicable):	Conversion coefficient from Air kerma to H*(10), $h^*_K= 1.46$ (according to BAS ISO 4037-3:2019)
Description of the equipment used for calibration:	The calibrations of the transfer chamber were performed against the IMBiH reference secondary-standard chamber, type PTW32002 s.n. 478, calibrated at the IAEA 27.09.2021. The distance between the focus and reference point of the chamber was 200 cm and the field size diameter 32.03 cm. HVL determined at the laboratory is 4.04 mm Cu. Ionization currents were measured using PTW UNIDOS Webline electrometer Type T10022 s.n. 298 based on charge measurement. Electrometer was calibrated in 2021 at the IAEA as a system consisting of reference ionization chamber and electrometer. No monitor chamber was used.
Description of calibration setup:	The IMBiH SSDL laboratory houses a high-stability generator and a bipolar tungsten-anode X RAY tube of type MXR-321, with a 3 mm beryllium window. Transfer chamber is oriented in such way that the Type and S/N are pointed towards the radiation source.

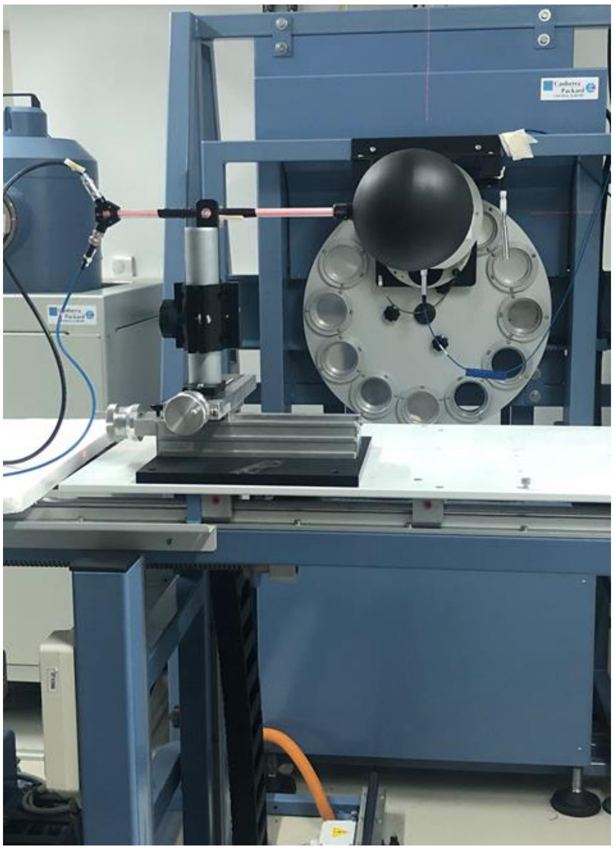
Picture of the calibration setup:



Determination of calibration coefficients (list all used corrections):	Basic formula that was used with all corrections, and description of the corrections, for example: $$N_H = \frac{Q_{ref} * N_{Ka} * k_{d,ref} * h_k}{Q_{user} * k_{d,user} * k_{elec}}$$ where ref and user denote reference measurements and measurements with transfer chamber, k_d is correction for air density, h_k conversion coefficient from air kerma to H*(10), kelec is electrometer calibration factor. The Q_{ref} and Q_{user} are corrected to the standard conditions of air temperature, pressure and relative humidity chosen for the comparison (T = 293.15 K, P = 101.325 kPa and h = 50%)
Calibration was performed by:	Amra Sabeta and Vedrana Makaric

IMBiH

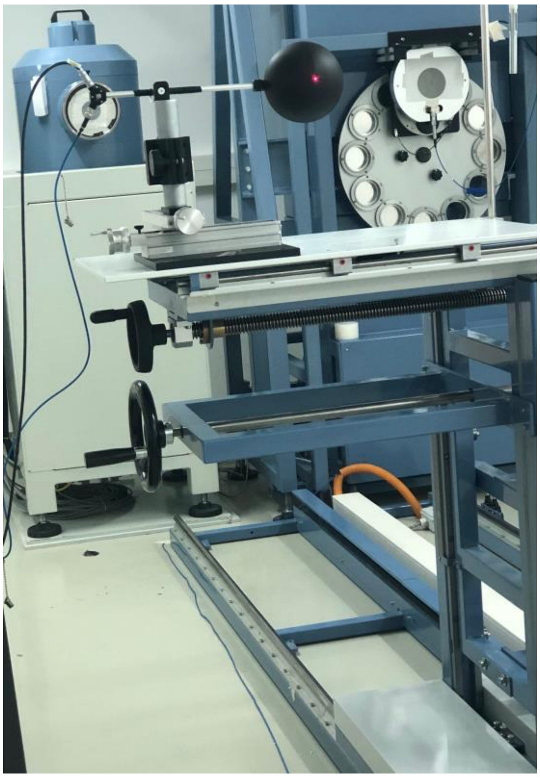
Calibration date/period:	**29.12.2021 - 4.01.2022**
Radiation quality:	N-300
Method of determination of H*(10):	Reference instrument is calibrated in terms of air kerma (Ka) by method of substitution, and conversion coefficient from Ka to H*(10) is used. The value of H*(10) was determined according to the standard BAS ISO 4037-3:2019 by using conversion coefficients $h^*_K(10;N)$ from air kerma free-in-air, Ka, to ambient dose equivalent, H*(10), for the radiation quality N: $\dot{H}^*(10)=\dot{K}a*h^*_K(10;N)$
Conversion factor value and source (if applicable):	Conversion coefficient from Air kerma to H*(10), h^*_K= 1.35 (according to BAS ISO 4037-3:2019)
Description of the equipment used for calibration:	The calibrations of the transfer chamber were performed against the IMBiH reference secondary-standard chamber, type PTW32002 s.n. 478, calibrated at the IAEA 27.09.2021. The distance between the focus and reference point of the chamber was 200 cm and the field size diameter 32.03 cm. HVL determined at the laboratory is 6.06 mm Cu. Ionization currents were measured using PTW UNIDOS Webline electrometer Type T10022 s.n. 298 based on charge measurement. Electrometer was calibrated in 2021 at the IAEA as a system consisting of reference ionization chamber and electrometer. No monitor chamber was used.
Description of calibration setup:	The IMBiH SSDL laboratory houses a high-stability generator and a bipolar tungsten-anode X RAY tube of type MXR-321, with a 3 mm beryllium window. Transfer chamber is oriented in such way that the Type and S/N are pointed towards the radiation source.

Picture of the calibration setup: 	
Determination of calibration coefficients (list all used corrections):	Basic formula that was used with all corrections, and description of the corrections, for example: $$N_H = \frac{Q_{ref} * N_{Ka} * k_{d,ref} * h_k}{Q_{user} * k_{d,user} * k_{elec}}$$ where ref and user denote reference measurements and measurements with transfer chamber, k_d is correction for air density, h_k conversion coefficient from air kerma to H*(10), kelec is electrometer calibration factor. The Q_{ref} and Q_{user} are corrected to the standard conditions of air temperature, pressure and relative humidity chosen for the comparison (T = 293.15 K, P = 101.325 kPa and h = 50%)
Calibration was performed by:	Amra Sabeta and Vedrana Makaric

IMBiH

Calibration date/period:	**16.11.2021 - 05.01.2022**
Radiation quality:	S-Cs
Method of determination of H*(10):	Reference instrument is calibrated in terms of air kerma (Ka) by method of substitution, and conversion coefficient from Ka to H*(10) is used. The value of H*(10) was determined according to the standard BAS ISO 4037-3:2019 by using conversion coefficients $h^*_K(10;S)$ from air kerma free-in-air, Ka, to ambient dose equivalent, H*(10) for the radiation quality S: $\dot{H}^*(10)=\dot{K}a*h^*K(10;S)$, where S is Cs-137 radiation source.
Conversion factor value and source (if applicable):	Conversion coefficient from Air kerma to H*(10), h^*_K= 1.21 (according to BAS ISO 4037-3:2019)
Description of the equipment used for calibration:	The calibrations of the transfer chamber were performed against the IMBiH reference secondary-standard chamber, type PTW32002 s.n. 478, calibrated at the IAEA in 2021. The distance between the focus and reference point of the chamber was 300 cm and the field size diameter 58.16 cm. Ionization currents were measured using PTW UNIDOS Webline electrometer Type T10022 s.n. 298 based on charge measurement. Electrometer was calibrated in 2021 at the IAEA.
Description of calibration setup:	The IMBiH SSDL laboratory houses a Single source Cs-137 irradiator Mod. IM1-P2 by TEMA SINERGIE s.r.l. with source activity 740 GBq (01.Nov.2012). The diameter of the circular beam at 3 m distance from the focus was 58.16 cm. Transfer chamber is oriented in such way that the Type and S/N are pointed towards the radiation source.

Picture of the calibration setup:



Determination of calibration coefficients (list all used corrections):	Basic formula that was used with all corrections, and description of the corrections, for example: $$N_H = \frac{Q_{ref} * N_{Ka} * k_{d,ref} * h_k}{Q_{user} * k_{d,user} * k_{elec}}$$ where ref and user denote reference measurements and measurements with transfer chamber, k_d is correction for air density, h_k conversion coefficient from air kerma to H*(10), kelec is electrometer calibration factor. The Q_{ref} and Q_{user} are corrected to the standard conditions of air temperature, pressure and relative humidity chosen for the comparison (T = 293.15 K, P = 101.325 kPa and h = 50%)
Calibration was performed by:	Amra Sabeta, Vedrana Makaric and Milica Stupar