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BIPM.RI(I)-K5 (BFKH 2025)

Measurement of air kerma for Caesium 137

KEY COMPARISON

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Key comparison BIPM.RI(I)-K5 of the air-kerma standards of the BFKH, Hungary and the BIPM in ^{137}Cs gamma radiation

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Abstract

A new indirect comparison of the standards for air kerma of the Budapest Főváros Kormányhivatala (BFKH), Hungary, and of the Bureau International des Poids et Mesures (BIPM) was carried out in the ^{137}Cs radiation beam using the radiation protection facility of the International Atomic Energy Agency (IAEA) in Seibersdorf, Austria, in August 2025^a. The comparison result, based on the calibration coefficients for one transfer chamber and expressed as a ratio of the BFKH and the BIPM standards for air kerma, is 1.0039 with a combined standard uncertainty of 3.1 parts in 10^3 . The results are analysed and presented in terms of degrees of equivalence, suitable for entry in the BIPM key comparison database, to update the 2009 comparison result.

1. Introduction

A new comparison of the standards for air kerma of the Budapest Főváros Kormányhivatala (BFKH), Hungary, and of the Bureau International des Poids et Mesures (BIPM) was carried out in August 2025 in the ^{137}Cs radiation beam at the International Atomic Energy Agency (IAEA) laboratories^a in Seibersdorf, Austria, to update the previous comparison result from 2009 (Kessler *et al.* 2010).

The comparison result is published in the BIPM key comparison database (KCDB 2026) under the reference BIPM.RI(I)-K5. The comparison was carried out after the implementation of the recommendations of ICRU Report 90 (ICRU 2016) at both laboratories.

The comparison was undertaken using a transfer ionization chamber belonging to the BFKH. Final results were supplied by the BFKH in February 2026.

2. Details of the standards and the transfer chambers

The air-kerma standard of the BFKH for ^{137}Cs comprises two nominally identical graphite-walled cavity ionization chambers, ND 1005, serial numbers 7707 and 7708, constructed in 1976 at the former laboratory Országos Mérésügyi Hivatal (OMH) (Csete 2001, Csete *et al.* 2002).

The BIPM standard, identified as CH6.3, is a parallel-plate, graphite-walled cavity ionization chamber with a volume of about 6.8 cm^3 (Boutillon and Niatel 1973, Burns *et al.* 2007, Kessler *et al.* 2009, Burns and Kessler 2018).

^a Since 2018, the BIPM no longer maintains reference radiation protection beams for ^{137}Cs and ^{60}Co . To continue the services of calibration and comparison (BIPM.RI(I)-K5) in ^{137}Cs beams, in 2022 the BIPM has installed the primary standard together with a BIPM measurement and data acquisition system at the IAEA laboratories in Seibersdorf, Austria.

Details of the BIPM and BFKH primary standards are given in Table 1; details of the BFKH transfer chamber used for the indirect comparison are given in Table 2.

Table 1. Characteristics of the BIPM and the BFKH standards

Dimensions		BIPM	BFKH	
		CH6.3 (paralell-plate)	ND 1005 - 7707	ND 1005 - 7708
Cavity	Diameter / mm	45.01	11	
	Thickness / mm	5.16	–	
	Height / mm	–	11	
	Measuring volume / cm ³	6.8313	1.0182	1.0227
Electrode	Diameter / mm	41.03	2	
	Thickness / mm	0.96	–	
	Height / mm	–	9	
Wall	Thickness / mm	2.98	4	
	Material	Graphite	Ultra-pure graphite EK51 Ringsdorf	
	Density / g cm ⁻³	1.85	1.75	
Voltage applied to outer electrode / V		±80	±250	

Table 2. Characteristics of the BFKH transfer chamber

Dimensions (nominal values)		ND 1001-7815 spherical
Chamber	Outer diameter / mm	38
Electrode	Diameter / mm	3
	Length / mm	15
Cavity	Volume / cm ³	20
Wall	Thickness / mm	2.5
	Material	Polyoxymethylene (POM)
Voltage applied to outer electrode / V		+250

3. Determination of the air kerma

For a cavity chamber with measuring volume V , the air-kerma rate is determined by the relation

$$\dot{K} = \frac{I}{\rho_{\text{air}} V} \frac{W}{e} \frac{1}{1-\bar{g}} \left(\frac{\mu_{\text{en}}}{\rho}\right)_{\text{a,c}} \bar{S}_{\text{c,a}} \prod k_i \quad (1)$$

where

- ρ_{air} is the density of air under reference conditions,
- I is the ionization current under the same conditions,
- W is the average energy spent by an electron of charge e to produce an ion pair in dry air,
- \bar{g} is the fraction of electron energy lost by radiative processes in air,
- $(\mu_{\text{en}}/\rho)_{\text{a,c}}$ is the ratio of the mean mass energy-absorption coefficients of air and graphite,
- $\bar{S}_{\text{c,a}}$ is the ratio of the mean mass electronic stopping powers for electrons in graphite and air,
- $\prod k_i$ is the product of the correction factors to be applied to the standard.

Physical data and correction factors

The values used for the physical constants, the correction factors, the volume of the primary standards entering in equation (1), and the associated uncertainties for the ^{137}Cs radiation beams at the IAEA and at the BFKH are given in Table 3.

Table 3. Physical constants and correction factors with their relative standard uncertainties of the BIPM and BFKH standards for the ^{137}Cs radiation beams

		BIPM		CH 6.3		BFKH		ND 1005 – 7707 ND 1005 - 7708	
		values	uncertainty ⁽¹⁾		values	uncertainty ⁽¹⁾			
			100 u_{iA}	100 u_{iB}		100 u_{iA}	100 u_{iB}		
Physical Constants									
ρ_{air}	dry air density ⁽²⁾ / kg m^{-3}	1.2930	–	0.01	1.2048	–	0.01		
$s_{c,a}$	ratio of mass stopping powers	1.0023	–	0.12 ⁽³⁾	1.0020	–	0.12 ⁽³⁾		
W/e	mean energy per charge / J C^{-1}	33.97	–		33.97	–			
$(\mu_{\text{en}}/\rho)_{a,c}$	ratio of mass energy-absorption coefficients	0.9990	0.01	0.04	0.9990	–	0.05		
\bar{g}	fraction of energy lost in radiative processes	0.0012	–	0.02	0.0012	–	0.02		
Correction factors									
k_s	recombination losses	1.0013	0.01	0.02	1.0020	0.01	0.02		
k_{pol}	polarity	–	–	–	1.0000	–	0.05		
k_h	humidity	0.9970	–	0.03	0.9970	–	0.03		
k_{st}	stem scattering	0.9998	0.01	–	0.9993	0.05	–		
k_{wall}	wall attenuation and scattering	1.0002	0.01	– ⁽⁴⁾	1.0278	0.01	0.08		
k_{an}	axial non-uniformity	1.0018	–	0.04	1.0005	0.07	0.05		
k_{rn}	radial non-uniformity	1.0009	–	0.05	1.0002	0.01	0.05		
k_{or}	orientation	0.9997	0.01	0.01	–	–	–		
Measurement of I / V									
V	chamber volume / cm^3	6.8313	–	0.08	⁽⁵⁾	0.10	0.05		
k_{vol}	volume correction	1.0004	–		–	–	–		
I	ionization current / pA	–	0.02	0.02	–	0.01	0.02		
	reproducibility	–	0.03	–	–	–	–		
	distance	–	–	–	–	0.02	–		
Relative standard uncertainty									
quadratic summation			0.04	0.17		0.13	0.19		
combined uncertainty			0.17			0.23			
Removing correlations			0.04	0.11		0.13	0.13		

⁽¹⁾ Expressed as one standard deviation

u_{iA} represents the type A relative standard uncertainty estimated by statistical methods

u_{iB} represents the type B relative standard uncertainty estimated by other means

⁽²⁾ At 101 325 Pa and 273.15 K for the BIPM and at 101 325 Pa and 293.15 K for the BFKH

⁽³⁾ Combined uncertainty for the product of $s_{c,a}$ and W/e . The recommendations of the ICRU were adopted by the BIPM in January 2019 (Burns and Kessler 2018) and by the BFKH, in 2021

⁽⁴⁾ The uncertainty for k_{wall} is included in the determination of the effective volume (Burns *et al* 2007)

⁽⁵⁾ See Table 1

The correction factors for the BFKH standard are described in Csete (2001) and Csete *et al.* (2002).

The air-kerma rate determination and measurement conditions at each laboratory are explained in the following paragraphs.

Reference values

The BIPM reference air-kerma rate \dot{K}_{BIPM} is taken as the mean of four measurements made during June and August 2025. The \dot{K}_{BIPM} value refers to an evacuated path length between source and standard corrected to the reference date of 2025-01-01, 0 h UTC, as is the ionization current measured using the transfer chamber. The half-life of ^{137}Cs was taken as 10 976 days ($u = 30$ days) (Bé *et al.* 2006). The correction for air attenuation between source and standard uses the ambient air density at the time of the measurement and the air attenuation coefficient 0.010 m^{-1} for ^{137}Cs .

At the BFKH, the \dot{K}_{BFKH} value was determined using the primary standards, evaluated as the mean of the measurements made during the period of the comparison. The \dot{K}_{BFKH} value is given at the date of 2025-08-05, 12 h UTC using the same half-life value for the decay correction as the BIPM.

Reference conditions and beam characteristics

The characteristics of the IAEA and BFKH beams are given in Table 4. The distance from source to reference plane is 1 m at both laboratories.

Table 4. Characteristics of the ^{137}Cs beams at the BFKH and the IAEA

^{137}Cs beam	Source dimensions / mm		Nominal $\dot{K} / \mu\text{Gy s}^{-1}$	Field diameter at 1 m / mm
	diameter	length		
BFKH source	15.5	23.0	70.8	260
IAEA source	14.3	19.9	16.7	230

4. Comparison procedure

The comparison of the BFKH and BIPM standards was made indirectly using the calibration coefficient for one transfer chamber given by

$$N_{K,\text{lab}} = \dot{K}_{\text{lab}} / I_{\text{lab}} \quad (2)$$

where \dot{K}_{lab} is the air-kerma rate and I_{lab} is the corrected ionization current of the transfer chamber measured by each laboratory.

The ionization chamber ND 1001, serial number 7815, belonging to the BFKH, is the transfer instrument used for this comparison. The main characteristics are listed in Table 2. The chamber was calibrated at the BFKH before and after the measurements made by the BIPM.

The BIPM and the BFKH experimental method for measurements and the correction factors applied to the current I_{lab} are described in the following paragraphs.

Positioning

At each laboratory the transfer chamber was positioned with the stem perpendicular to the beam direction and with the appropriate marking on the stem facing the source. At the IAEA, the transfer chamber was set-up and measured by the BIPM on three separate occasions after being repositioned each time.

Applied voltage and polarity

At both laboratories, the collecting voltage and polarity indicated in Table 2 were applied to the outer electrode of the BFKH transfer chambers at least 40 min before any measurements were made.

Charge and leakage measurements

The charge Q collected by the BFKH chambers was measured by the BIPM at the IAEA using a Keithley electrometer, model 6517B. The source is exposed during the entire measurement series, and the charge is collected for the appropriate, electronically controlled, time interval. A pre-irradiation was made for at least 40 min before any measurements. The measurements were corrected by the mean leakage current measured before and after each series of measurements. The measured leakage values were around 3 fA, 2 parts in 10^4 in relative terms of the ionization current.

At the BFKH, the charge Q collected by the transfer chamber was measured using a Hungarian-developed measurement system known as the PAM electrometer, model 2009. A pre-irradiation of at least 30 min was made before any measurements. The measurements were corrected for the leakage current measured after each series of measurements. The measured leakage values were around 4 fA, less than 1 part in 10^4 in relative terms of the ionization current.

Radial and axial non-uniformity correction

The correction for the radial non-uniformity of the beam for the transfer chamber at both laboratories is less than 5 parts in 10^4 . No correction was applied to the measured current for the radial non-uniformity of the beam and a relative uncertainty component of 2 parts in 10^4 is included in Table 7.

Ion recombination

The correction factor for losses due to ion recombination was determined at the BFKH for the comparison run in 2009 (Kessler *et al.* 2010) using the method of Niatel as described in Boutillon (1998). For the IAEA and BFKH air kerma rate values, volume recombination is negligible, and initial recombination is the same for both beams. Consequently, no correction was applied and a relative standard uncertainty of 2 parts in 10^4 is included in Table 7.

Ambient conditions

During a series of measurements, the air temperature is measured for each current measurement and was stable to better than 0.2 °C at the IAEA. At the BFKH, the air temperature was stable to better than 0.2 °C during each series of measurements. At both laboratories, the current measured using the transfer chambers is normalized to the reference conditions of 293.15 K and 101.325 kPa.

Relative humidity is controlled, and it was between 45 % and 55 % at the IAEA and between 44 % and 48 % at the BFKH.

5. Results of the comparison

The result of the comparison R_K is expressed in the form

$$R_K = N_{K,BFKH}/N_{K,BIPM} \quad (3)$$

in which the average value of measurements made at the BFKH before and after those made at the IAEA by the BIPM is compared with the mean of the measurements made by the BIPM.

Table 5 lists the relevant values of N_K at the stated reference conditions (293.15 K and 101.325 kPa) and the final results of the indirect comparison.

Table 5. Result of the indirect comparison of the ^{137}Cs air kerma standards

Transfer chambers	$N_{K,\text{BFKH}} / \text{Gy } \mu\text{C}^{-1}$			$N_{K,\text{BIPM}} / \text{Gy } \mu\text{C}^{-1}$	R_K	u_c
	pre-BIPM	post-BIPM	overall mean			
ND 1001-7815	1.4855	1.4817	1.4836	1.4779	1.0039	0.0031

The uncertainties associated with the calibration of the transfer chamber at each laboratory and with the indirect comparison are presented in Table 6 and Table 7, respectively. The reproducibility at the IAEA and at the BFKH are estimated to be 1 part in 10^4 and 1.3 parts in 10^3 , respectively; these values are included in Table 6.

The values $N_{K,\text{BFKH}}$ measured before and after the measurements at the BIPM give rise to a relative standard deviation taken as a representation of the stability of the transfer instrument. The short-term stability thus evaluated is included in Table 7 and it was estimated to be 1.8 parts in 10^3 .

Table 6. Uncertainties associated with the transfer chamber calibration

Relative standard uncertainty	BIPM		BFKH	
	100 u_{iA}	100 u_{iB}	100 u_{iA}	100 u_{iB}
Air-kerma rate	0.04	0.17	0.13	0.19
Ionization current for the transfer chambers	0.01	0.02	0.01	0.02
Distance	0.01	–	0.02	–
Reproducibility	0.01	–	0.13	–
Temperature, pressure	–	–	–	0.01
$N_{K,\text{lab}}$	0.05	0.17	0.19	0.19

Table 7. Uncertainties associated with the indirect comparison

Relative standard uncertainty	100 u_{iA}	100 u_{iB}
$N_{K,\text{BFKH}} / N_{K,\text{BIPM}}$	0.19	0.17 ⁽¹⁾
Ion recombination	–	0.02
Radial non-uniformity	–	0.02
Stability of the chambers	0.18	–
$R_{K,\text{BFKH}}$	$u_c = 0.0031$	

⁽¹⁾ The combined standard uncertainty of the comparison result takes into account correlation in the type B uncertainties associated with the physical constants and the humidity correction

Some uncertainties in \dot{K}_{air} that appear in both the BIPM and the BFKH determinations (namely air density, W/e , $(\mu_{\text{en}}/\rho)_{\text{a,c}}$, \bar{g} , $s_{\text{c,a}}$ and k_{h}) cancel when evaluating the uncertainty of the ratio R_K of the BFKH and BIPM calibration coefficients.

The ratio of the air-kerma calibration coefficients of the transfer chamber determined by the BFKH and the BIPM taken from Table 5 is 1.0039 with a combined standard uncertainty, u_c , of 0.0031.

6. Degrees of equivalence

Following a decision of the CCRI, the BIPM determination of the dosimetric quantity, here K_{BIPM} , is taken as the key comparison reference value (KCRV) (Allisy *et al.* 2009). It follows that for each NMI i having a BIPM comparison result x_i with combined standard uncertainty u_i , the degree of equivalence with respect to the reference value is the relative difference $D_i = (K_i - K_{\text{BIPM},i}) / K_{\text{BIPM},i} = x_i - 1$ and its expanded uncertainty $U_i = 2 u_i$.

The results for D_i and U_i are usually expressed in mGy/Gy. Table 8 gives the values for D_i and U_i for each NMI, i , taken from the KCDB of the CIPM MRA (1999) and this report. These data are presented graphically in Figure 1.

Note that the data presented in Table 8, while correct at the time of publication of the present report, become out-of-date as NMIs make new comparisons. In addition, revised validity rules for comparison data have been agreed by the CCRI(I) so that any results older than 15 years are no longer considered valid and have been removed from the KCDB. The formal results under the CIPM MRA are those available in the key comparison database.

Table 8. Degrees of equivalence

For each laboratory i , the degree of equivalence with respect to the key comparison reference value is the difference D_i and its expanded uncertainty U_i . Tables formatted as they appear in the BIPM key comparison database

BIPM.RI(I)-K5

Lab i	D_i	U_i
	/ (mGy/Gy)	
NIST	-1.0	7.0
NMIJ	-2.3	5.2
PTB	2.4	5.4
NIM	-3.3	4.2
ININ	4.8	4.0
VSL	-4.8	7.6
SMU	5.1	5.4
BEV	4.3	5.4
CIEMAT	-0.8	4.4
GUM	0.5	5.6
LNE-LNHB	-3.0	4.4
KRISS	-0.8	4.0
BFKH	3.9	6.2

EURAMET.RI(I)-K5.1

Lab i	D_i	U_i
	/ (mGy/Gy)	
VINS	-3.3	20.2

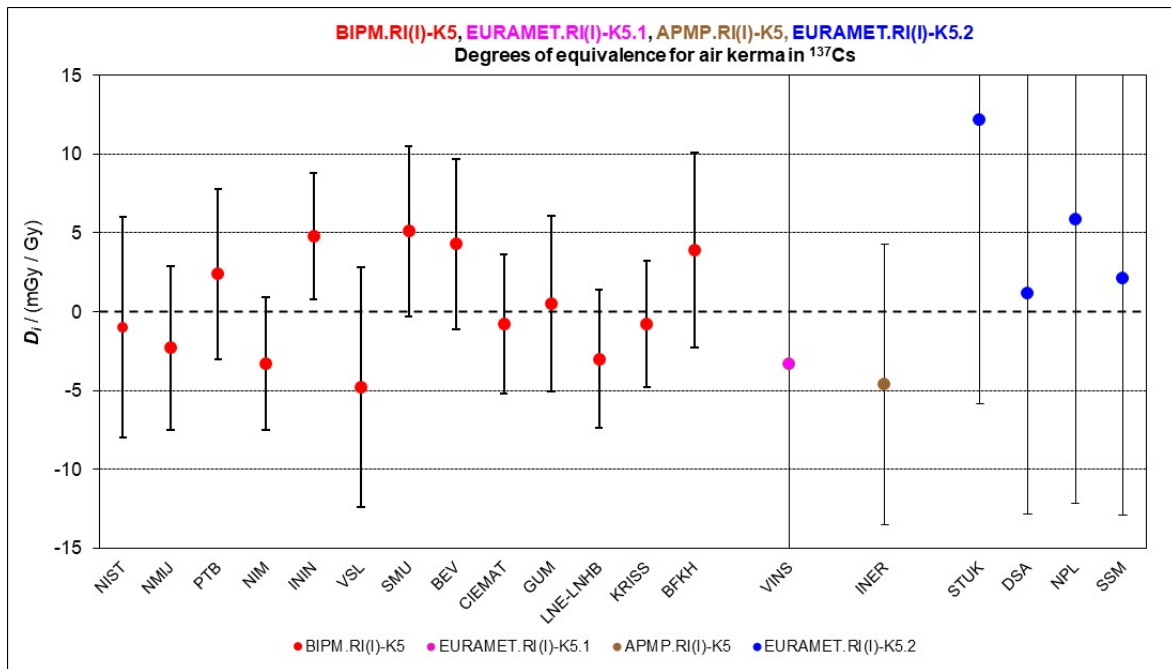
APMP.RI(I)-K5

Lab i	D_i	U_i
	/ (mGy/Gy)	
INER	-4.6	8.9

EURAMET.RI(I)-K5.2

Lab i	D_i	U_i
	/ (mGy/Gy)	
STUK	12.2	18.0
DSA	1.1	14.0
NPL	5.8	18.0
SSM	2.1	15.0

Figure 1. Graph of degrees of equivalence with the KCRV



7. Conclusion

The previous comparison of the BFKH and BIPM standards for air kerma in ¹³⁷Cs beam was made in 2009 at the BIPM using the same transfer chamber. The result of the indirect comparison was 1.0053 (25).

Since the previous comparison, both laboratories implemented some changes in the standards following the recommendations of the ICRU 90. For both the BFKH and the BIPM, this resulted in a reduction of 8 parts in 10³ in the determination of air kerma; consequently, the 2009 result remains unchanged.

The present comparison made indirectly using the same transfer chamber gives a result of 1.0039 (31), in agreement within the uncertainties with the 2009 result.

The BFKH is in agreement within the expanded uncertainty with all the NMIs having taken part in the BIPM.RI(I)-K5 ongoing key comparison for air-kerma standards in ¹³⁷Cs gamma-ray beams.

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