Report on the BIPM neutron-dosimetry intercomparison

by V.D. Huynh

Bureau International des Poids et Mesures, F-92310 SEVRES

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I - Introduction

Under the auspices of Section III (Mesures neutroniques) of the Comité Consultatif pour les Etalons de Mesure des Rayonnements Ionisants (CCEMRI), a neutron-dosimetry intercomparison has been organized by the BIPM*. This comparison, which started at the end of 1985, consisted in circulating to one participant after the other the transfer instruments supplied by the BIPM. The measurements, restricted to free-in-air conditions, have been completed at the BIPM, TNO, NPL, PTB, ETL, NBS, IAEB and the NIM. The reference equipment will continue to be available on a permanent basis, on request, for the benefit of laboratories entering the field of neutron dosimetry later on.

The purpose of the comparison is to compare, under specified (reference) conditions, the kerma values for neutron and gamma components, K_N, K_G and $K_{tot} = K_N + K_G$, in A-150 plastic per unit of reference monitor in the local mixed field, as measured with the BIPM equipment and with the local dosimetry systems.

In the comparison, all participating laboratories used the (d+T) reaction with average neutron energies ranging from 14.6 to 15 MeV, except for the NBS which has two groups of neutrons with average energies of 17.5 and 4.7 MeV produced by the (d+T) and (d+D) reactions, respectively (Table 4b). The checks on the BIPM equipment have been made at the BIPM before and after the use of the instruments at each participating laboratory, to ensure the proper functioning and to test for any possible changes. The photon calibration factors for the BIPM dosimeters, measured at the BIPM and at the participating laboratories, are also intercompared.

II - Principle of mixed-field dosimetry

The neutron and photon components (K_N and K_G), of the kerma value in A-150 plastic of a mixed field (per unit of reference monitor), are generally measured using a combination of an A-150 plastic tissue-equivalent (TE) ionization chamber (parameters designated in the following by the subscript T) which measures the total kerma, and a "neutron insensitive" dosimeter (parameters designated by the subscript U). The former usually has a sensitivity to neutrons relative to its sensitivity to the gamma rays used for the photon calibration, k_T, of about unity, whilst the latter is chosen to give a relative neutron sensitivity, k_U, which is as low as possible. The responses R'_T and R'_U per unit of reference monitor in the mixed field, expressed as the quotients of the responses of the two dosimeters by their sensitivities

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* For the list of abbreviations, see Table 1, p. 13.

to the gamma rays used for calibration, are given respectively by

$$R_T' = k_T K_N + h_T K_G \quad \text{and} \tag{1}$$

$$R_U' = k_U K_N + h_U K_G . \tag{2}$$

It is usual to assume that h_T and h_U are unity. From Eq. (1) and (2) the values of K_N and K_G can be derived. They may be expressed as

$$K_N = \frac{R_T' - R_U'}{k_T - k_U} \quad \text{and} \tag{3}$$

$$K_G = \frac{k_T R_U' - k_U R_T'}{k_T - k_U} . \tag{4}$$

The uncertainty in K_N, denoted by δK_N, may be expressed in terms of those in R_T', R_U', k_T and k_U as

$$(\delta K_N)^2 = [(\delta R_T')^2 + (\delta R_U')^2 + (K_N \delta k_T)^2 + (K_N \delta k_U)^2]/(k_T - k_U)^2 , \tag{5}$$

and the expressions for the uncertainties in the photon and total kerma, δK_G and δK_{tot}, contain similar terms. The terms due to δh_T and δh_U are not included.

The relative response R_T' of the dosimeter T (TE chamber) in the mixed field can be expressed explicitly by the relation

$$R_T' = Q_T (k_s k_p k_w k_{st} k_l k_f) \alpha_{T,c} , \tag{6}$$

where

Q_T is the total charge measured in the cavity volume of the ionization chamber at the reference pressure and temperature,

k_s, k_p, k_w, k_{st}, k_l and k_f are the correction factors for lack of saturation, polarity effect, wall, stem, leakage current and gas flow effect, respectively, and

$\alpha_{T,c}$ is the kerma calibration factor which is defined by

$$\alpha_{T,c} = f_c X_{ch}/(Q_T k_s k_p k_w k_{st} k_l k_f)_c , \tag{7}$$

where

f_c is the conversion factor from exposure to kerma in A-150 plastic,

X_{ch} is the exposure in free air at the centre of the ionization chamber in the absence of the chamber,

Q_T, k_s, k_p, k_w, k_{st}, k_1 and k_f have the same meaning as in Eq. (6);

the subscript c refers to the gamma rays used for calibration.

In the comparison, a Geiger-Müller counter (GM) and a magnesium-argon chamber (Mg/Ar) have been used as "neutron-insensitive" dosimeters. The relative response, R'_U, for the GM counter in the mixed field can be expressed explicitly by

$$R'_U = N_{GM} \, \alpha_{GM,c} \, , \tag{8}$$

where N_{GM} is the count rate of the GM counter in the mixed field and $\alpha_{GM,c}$ is the photon-kerma calibration factor (similar to Eq. (7)), which is defined by

$$\alpha_{GM,c} = f_c \, \dot{X}_{GM}/(N_{GM})_c \, , \tag{9}$$

where $\dot{X}_{GM}$ is the exposure rate free in air at the centre of the GM counter in the absence of the counter, and $(N_{GM})_c$ is the count rate of the GM counter in the calibrated gamma-ray beam.

For the relative response R'_U of the Mg/Ar chamber there are relations similar to those given in Eq. (6) and (7).

The explicit expression for k_T is given in references [1] to [3] whereas the values of k_U for the BIPM GM counter and the Mg/Ar chamber are measured at BIPM.

III - Equipment and measurement conditions with BIPM dosimeters

The BIPM equipment consists of

- two Exradin T2-type TE ionization chambers + TE build-up caps with wall thicknesses of 1, 2, 3, 4, 5 and 6 mm,
- one Exradin MG2-type ionization chamber + Mg build-up caps with wall thicknesses of 1, 2, 3, 4, 5 and 6 mm,

- one GM counter type ZP1311 (+ spare tube),
- 60 m of triaxial cable with BNC connectors and "banana" plugs + adaptor connectors,
- one flow-rate meter (floating-ball type).

The instructions for the use of the dosimeters and for tests of proper functioning of the equipment are given in the "Measurement protocol for BIPM neutron dosimetry intercomparison" accompanying the equipment.

1. Equipment for charge measurements and gas flow

The type of electrometer, the gas-flow system and the chemical composition of TE and Ar gases used by each participating laboratory (LAB) are summarized in Table 1. Only the BIPM and the PTB have used the added tubing to the outlets of the ionization chambers for the gas-flow system, so that the pressure in the cavity volume of the chamber is determined by the mean value of two pressures measured in the gas-flow circuit at the points situated respectively before (inlet) and after (outlet) the chamber. For some laboratories (such as NPL), the responses of the chambers are corrected for the slight excess of pressure above atmospheric. The gas-flow rates used by all participants are about 25 cm^3 min^{-1}, except for ETL which used a gas-flow rate of 40 cm^3 min^{-1} for Ar.

2. Photon-calibration conditions

a) Ionization chambers

The type and manufacturer of the photon sources, the field size, the distance of chambers from the centre of the source and the exposure rate at chamber positions are summarized in Table 2. One can see that, on the one hand, all participants used ^{60}Co as photon calibration source (except for the TNO and the NPL which preferred a source of ^{137}Cs) and that, on the other hand, only the PTB and the NBS used the exposure standards which were determined with the revised values for the stopping powers of electrons.

b) GM counters

The type of photon sources, the field size, the distance of the GM counters from the centre of the source, the exposure rate at the GM-counter position and the dead time are summarized in Table 3. One can observe that the dead times used by the participants varied from 20 to 64 μs.

3. Neutron-field measurement conditions

Table 4a summarizes the experimental conditions for the measurements in the neutron fields. All participants used only the (d+T) neutrons. The information concerning the neutron spectrum given by each participating laboratory is summarized in Table 4b.

IV - Results

1. Measurements with BIPM dosimeters

a) Photon-calibration measurements

The responses, R(TE) and R(Ar), of the TE and Mg chambers flushed respectively with TE gas and with Ar, relative to their responses, R(dry air), when the chambers are filled with air, are given in Table 5 for all participants. From this table one can see that the ratios of responses, R(TE)/R(dry air), for the BIPM TE chambers, measured at BIPM, are in good agreement with those measured at the participating laboratories, whilst the ratios of responses, R(Ar)/R(dry air), for the BIPM Mg chambers, measured at the BIPM, are on an average about 2 % lower than those measured by the other laboratories.

The results of photon-kerma calibration factors obtained at the BIPM, $\alpha_{c(BIPM)}$, and at participating laboratories, $\alpha_{c(LAB)}$, are summarized in Table 6 for TE chambers (n° 266, 199 and 250), and in Table 7 for GM counter (GM3) and Mg chamber (n° 139). In these tables the values of α_c have been calculated with a value of f_c = 9.63 mGy•R^{-1} for all participants, except for the PTB which used a value of 9.65 mGy•R^{-1}. It should be pointed out that the agreement between the LAB and BIPM calibration factors seems to be slightly better with the values of $\alpha_{c(BIPM)}$ taken from those obtained before sending the BIPM equipment to the participants, instead of the values taken from the mean values obtained before and after LAB measurements (see Table 8). In this report only the values of $\alpha_{c(BIPM)}$ taken from those obtained before LAB measurements are used to analyze the results of the comparison.

For illustration, Figure 1 shows the variation of $\alpha_{c(BIPM)}$ for BIPM TE chamber n° 266 and Mg chamber n° 139 during the period of comparison, and Figure 2 gives the results of comparison on the ratios of $\alpha_{c(LAB)}/\alpha_{c(BIPM)}$ for TE chamber n° 266, GM counter n° 3 and Mg chamber n° 139.

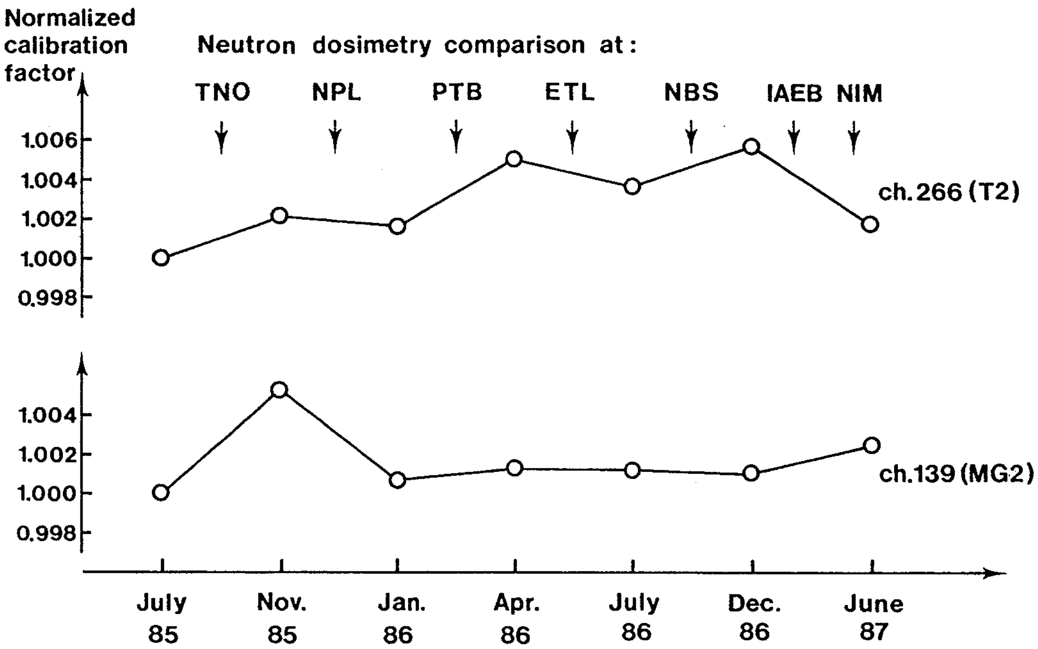

Fig. 1 - Variation of the photon calibration factors for the BIPM TE chamber (n° 266) and Mg chamber (n° 139) during the period of comparison.

Table 9 gives the correction factors k_s, k_p, k_w, k_{st}, k_l and k_f, determined by each participant for the TE and Mg chambers. From this table, one can observe that these correction factors, which are used to calculate the values of α_c (see Eq. (7)), present some differences from laboratory to laboratory. In order to see if there is a better agreement in the results of comparison for α_c, a set of normalized correction factors, specially for k_s and k_w, has been chosen for all participants (see Table 10). The results of this analysis are given in Table 11, which is similar to Table 8. Unfortunately, no improvement can be observed by comparing Tables 8 and 11.

b) Neutron-field measurements

The values of R'_T determined by each participating laboratory, $R'_{T(LAB)}$, for TE chambers are given in Table 12. In this table, the ratios of $R'_{T(LAB)}/R'_{T(BIPM)}$ as well as the mean values of R'_T for the two TE chambers used are also included. Similarly, the values of $R'_{U(LAB)}$ and the ratios of $R'_{U(LAB)}/R'_{U(BIPM)}$ for the GM counter and Mg chamber are given in Table 13. It should be noted that the values of $R'_{T(BIPM)}$ and $R'_{U(BIPM)}$ are the values obtained with the BIPM calibration factors. Table 14 gives the correction factors which are used to calculate the values of R'_T and R'_U (see Eq. (6)) for the TE and Mg chambers by all participants. Here one can observe again that there are some differences from one laboratory to the other for these correction factors. In order to check if there is a better agreement in the results of comparison for R'_T and R'_U, a set of normalized correction factors, specially for k_s and k_w, has been chosen for all participants (see Table 15). The results of this analysis, given in Table 16, seem to indicate, in general, a better agreement between the LAB and BIPM determinations when the normalized correction factors have been used (by comparing Tables 12, 13 and 16).

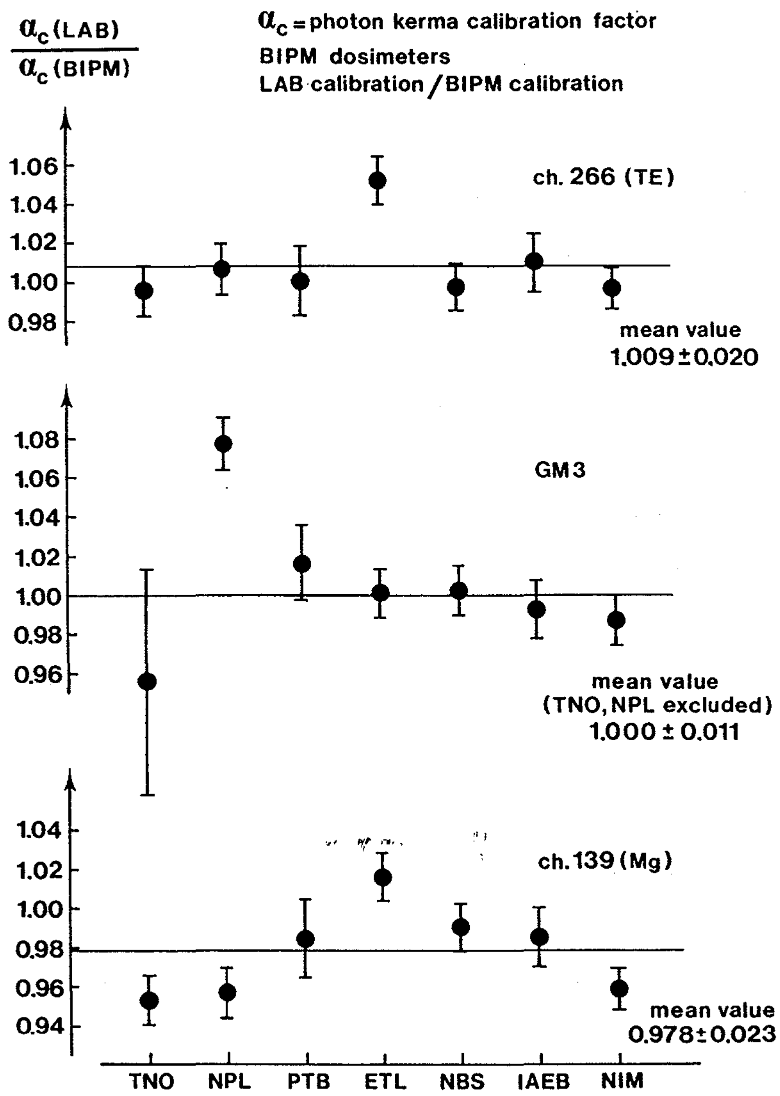

Fig. 2 - Ratios of LAB-to-BIPM photon kerma calibration factors, $\alpha_{c(LAB)}/\alpha_{c(BIPM)}$, for the BIPM dosimeters.
All participants used ^{60}Co, except for the TNO and the NPL which used ^{137}Cs.

c) Kerma values for A-150 plastic

The kerma values, K_N, K_G and K_{tot}, for A-150 plastic, obtained with the BIPM dosimeters and determined by each participating laboratory are given in Table 17. The values of R'_T, R'_U, k_T and k_U, which are used to calculate these kerma values, are also given, according to the combinations (TE chamber + GM) and (TE chamber + Mg chamber), respectively. It should be noted that the values of R'_T are the mean values obtained with the two TE chambers used by each participant, except for the NBS which used only one TE chamber (n° 266) because the second one (n° 199) had been broken.

In Table 17 the results obtained by using the LAB calibration factors relative to those obtained by using the BIPM calibration factors are also indicated.

2. Measurements with local dosimetry systems

a) Local dosimeters used in the comparison

All participating laboratories used a TE chamber, a GM counter and an Mg chamber in the comparison, except for the NIM which used no Mg chamber, and for the NBS which used four TE chambers, three Mg chambers and one GM counter. Table 18 summarizes the types of local dosimeters used in the comparison.

The values of R'_T and R'_U obtained with the local dosimeters, as well as the values of k_U and K_G/K_{tot}, are given in Table 19.

b) Comparison of the kerma values obtained by local dosimeters and by BIPM dosimeters

The results of the comparison of kerma values for A-150 plastic are given in Tables 20 and 21. Table 20 gives the values of R'_T, K_N, K_G and K_{tot}, as well as their combined uncertainties (1 standard deviation), obtained with local dosimeters relative to those obtained with BIPM dosimeters which are calibrated at the BIPM. Similarly, Table 21 gives the results obtained with local dosimeters relative to those obtained with BIPM dosimeters which are calibrated at the participating laboratories. In order to have some indication of the differences in k_U values, the values of K_G/K_{tot} determined with local dosimeters and with BIPM dosimeters are given in Table 22. The combined relative uncertainties (1 standard deviation) for α_c, R'_T, R'_U and k_U, given by each participating laboratory, for BIPM dosimeter and local dosimeter measurements, are summarized in Table 23. The uncertainties due to k_T are not included for the intercomparison purpose. The values of $K_{N(LAB)}/K_{N(BIPM)}$ obtained with the BIPM dosimeters and the values of K_N obtained with local dosimeters, relative to those obtained with the BIPM dosimeters (LAB and BIPM calibrations, respectively), are also given in Figures 3, 4 and 5.

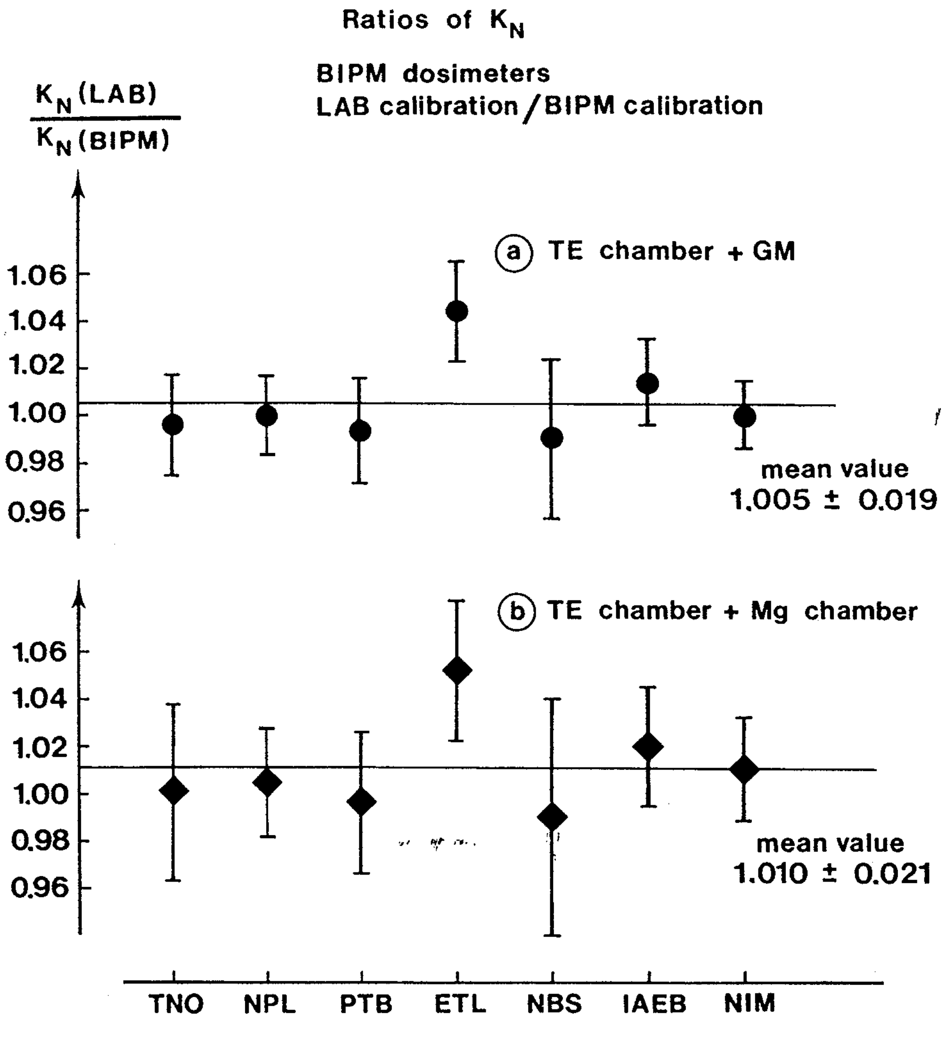

Fig. 3 – Ratios of $K_{N(LAB)}/K_{N(BIPM)}$ obtained with BIPM dosimeters. $K_{N(LAB)}$ and $K_{N(BIPM)}$ are the values of K_N determined by using the LAB calibration factors and BIPM calibration factors, respectively.

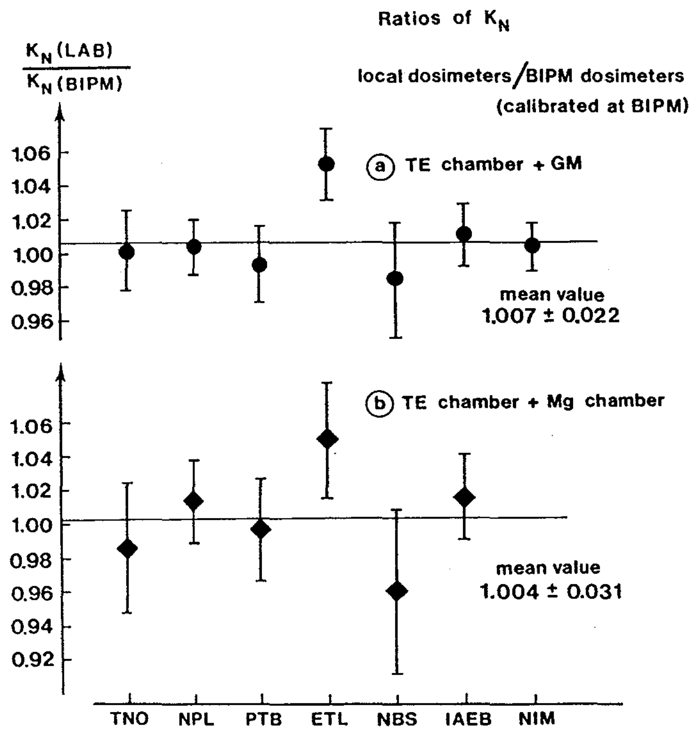

Fig. 4 - Values of K_N obtained with local dosimeters relative to those obtained with the BIPM dosimeters calibrated at BIPM.

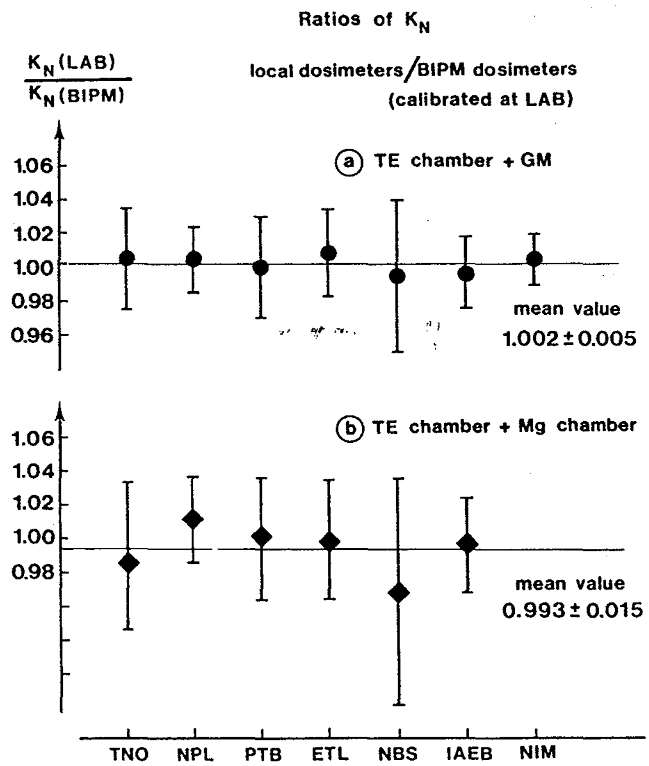

Fig. 5 - Values of K_N obtained with local dosimeters relative to those obtained with the BIPM dosimeters calibrated at the participating laboratories.

V - Discussion and conclusion

We can make the following observations concerning this comparison.

1. In the photon calibration of BIPM dosimeters, a slightly better agreement has been generally observed between the LAB and the BIPM determinations when the BIPM calibration factors were taken from the measurements carried out just before sending the BIPM equipment to the participants, and not the mean values taken from the measurements performed before and after the LAB calibration (Table 8).

2. In the photon calibration measurements, the calibration factors for BIPM TE chambers are in good agreement (spread of about 1 %, Fig. 2) between the values measured at the participating laboratories and at the BIPM (except for the ETL). However, for the BIPM Mg chamber the values of the calibration factors obtained at the BIPM are on average about 2 % higher than those obtained at the participating laboratories (Table 8 and Fig. 2). The latter results can also be shown by the ratios of responses of the Mg chamber flushed with Ar to those of the chamber filled with air (Table 5). It seems to indicate that the response of the BIPM Mg chamber, measured at the BIPM, was too low (about 2 %) when the chamber was flushed with Ar.

3. For the BIPM TE and Mg chambers, by using a set of normalized correction factors in the charge measurements for all participants, no improvement has been observed for the photon-calibration factors between the BIPM and LAB determinations (Tables 8 and 11), but it seems to give a better agreement for neutron-field measurements (Tables 12, 13 and 16).

4. For a proper use of the BIPM GM counter, the photon dose rate should not exceed 150 μGy min^{-1}. The dead time of this counter depends strongly on the dose rate used. A great spread of dead times (20 to 64 μs) has been observed among the values obtained by different participants (Table 3).

5. Except for the ETL, the results of the comparison with the BIPM dosimeters show that there is a good agreement (spread of about 1 %, Fig. 3) between the kerma values of K_N(or K_{tot}) obtained by using the BIPM calibration factors and those obtained by the local calibration factors measured at the participating laboratories (Table 17). Similar results are obtained if one compares the K_N (or K_{tot}) values determined by the BIPM dosimeters (calibrated at the BIPM) to those determined by the local dosimeters (Table 20 and Fig. 4).

6. The kerma values determined with the BIPM dosimeters by using the local calibration factors compared to the kerma values obtained with the local dosimeters are generally in better agreement than those obtained by using the BIPM calibration factors. The case of the ETL is particularly interesting, since the values of K_N (or K_{tot}) obtained with the ETL calibration factors are in good agreement with the values measured with the ETL dosimeters, whilst there is a difference of about 5 % when the calibration factors are taken from the BIPM determination (Fig. 4 and 5).

7. The K_G values show a large difference (up to 50 %) between the values obtained by the BIPM dosimeters and by the local dosimeters. A similar difference exists if one uses only the BIPM dosimeters, but calibrated at the BIPM and at the participating laboratories, respectively. Fortunately, the contribution of the photon component, K_G, to the total kerma, K_{tot}, is small (1 to 6 %) for all laboratories (Table 22), so that its influence on the determination of the neutron kerma, K_N, is also small. It should be pointed out that this difference in K_G values has been observed by using the GM counter as well as by using the Mg chamber to separate the photon component from the total kerma, although a better agreement is generally obtained with the GM counter. One can observe from Tables 20 and 21 that the uncertainties associated with the Mg chamber measurements are much bigger than those associated with the GM counter measurements, due to the higher values of k_U for Mg chambers.

Acknowledgments

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Table 1. Equipment for charge measurement and gas flow

LAB*	Electrometer	Gas flow system	Chemical composition: TE gas CH_4 (%)	TE gas CO_2 (%)	TE gas N_2 (%)	Ar Purity (%)
BIPM	CARY 401	With tubes connected to the gas outlets of chambers	64.0	32.9	3.1	99.9999
TNO	Keithley 616	No added tubing to the gas outlets of chambers	64.2	32.6	3.18	99.9999
NPL	Dual MOSFET (NPL design)	No added tubing to the gas outlets of chambers	64.4	32.2	3.2	99.99
PTB	Keithley 642	With tubes connected to the gas outlets of chambers	64.4	32.4	3.2	99.9996
ETL	TR-8401 (Advantest)	No added tubing to the gas outlets of chambers	66.4	30.4	3.2	99.995
NBS	Keithley 642	No added tubing to the gas outlets of chambers	64.8	31.7	3.51	99.998
IAEB	Keithley 602 Keithley 617	No added tubing to the gas outlets of chambers	65.44	32.1	2.56	99.99
NIM	Keithley 616 JF-64	No added tubing to the gas outlets of chambers	65.1	31.9	3.2	99.99

* Given in chronological order of participation, the acronyms stand for:
BIPM: Bureau International des Poids et Mesures, Sèvres, France
TNO: Radiobiological Institute, Rijswijk, The Netherlands
NPL: National Physical Laboratory, Teddington, United Kingdom
PTB: Physikalisch-Technische Bundesanstalt, Braunschweig, Federal Republic of Germany
ETL: Electrotechnical Laboratory, Ibaraki, Japan
NBS: National Bureau of Standards, Gaithersburg, MD, USA
IAEB: Institute of Atomic Energy, Beijing, People's Republic of China
NIM: National Institute of Metrology, Beijing, People's Rep. of China

Table 2. Photon calibration conditions for ionization chamber measurements

LAB	Type and manufacturer of photon source	Field size	Distance (cm)	Exposure rate (A/kg)	
BIPM	^{60}Co NBS gift	10 cm x 10 cm	100	6.048×10^{-6}	
TNO	^{137}Cs Shepherd model 81 irradiator	Ø 20 cm	30.91	5.072×10^{-6}	
NPL	^{137}Cs Mainance Ltd	Ø 12 cm	60	1.459×10^{-6}	
PTB	^{60}Co Buchler/Amersham X.54/2	Ø 8 cm	100	4.110×10^{-7}	*
ETL	^{60}Co AECL,JRIA	Ø 45 cm	400	1.355×10^{-5}	
NBS	^{60}Co Atomic Energy of Canada Ltd.	Ø 4.9 cm	63.5	2.694×10^{-6}	*
IAEB	^{60}Co Amersham International Inc.	8 cm x 8 cm	40	4.512×10^{-5}	
NIM	^{60}Co Teletherapy service made in China	10 cm x 10 cm	75	1.257×10^{-5}	

* : the exposure rates given by PTB and NBS are obtained with the revised values for the stopping powers of electrons

Table 3. Photon calibration conditions for GM counter measurements

LAB	Type of photon source	Field size	Distance (cm)	Exposure rate (A/kg)	Dead time (μs)
BIPM	^{60}Co	10 cm x 10 cm	100	6.533×10^{-9}	33.03
TNO	^{137}Cs	Ø 130 cm	200	1.211×10^{-7}	20
NPL	^{137}Cs	Ø 40 cm	100	1.619×10^{-7}	20
PTB	^{60}Co	Ø 16 cm	200	5.196×10^{-8} *	22
ETL	^{60}Co	Ø 25 cm	100	2.102×10^{-8}	20
NBS	^{60}Co	Ø 25.9 cm	199.9	3.019×10^{-8} *	64
IAEB	^{60}Co	Open	35.05	2.616×10^{-8}	20
NIM	^{60}Co	Open	30	3.492×10^{-8}	20

* : the exposure rates given by PTB and NBS are obtained with the revised values for the stopping powers of electrons

Table 4a . Experimental conditions for measurements in the (d+T) neutron fields

LAB	Type of accelerator	Incident deuteron energy (MeV)	Field size	Distance and angle	Monitor (distance and angle)
BIPM	Sames J150	0.140	Open	30 cm 26°7	Associated α particle (1 m, 150°)
TNO	Van de Graaff K2N-3750	1.0	6 cm x 8 cm at collimator exit	52.5 cm 0°	Disc-type transmission chamber inserted in the collimator duct
NPL	Sames J150	0.150	Open	30 cm 20°	Associated α particle (90 cm, 150°); TE chamber (20 cm, 0°)
PTB	Van de Graaff HVC, 3.75 MeV	0.400	Open	30 cm	Beam charge integrator; Long counter (5.5 m, 100°); BF3 counter (5.5 m, 130°); He-3 counter (85 cm, 145°); GM counter (45 cm, 180°)
ETL	Cockcroft-Walton (World Engineering Co., Ltd)	0.220	Open	10 cm 45°	Associated α particle (1 m, 90°7)
NBS	Van de Graaff HVC, 3 MV	1.7	Open	10 cm	A-150 plastic spherical chamber (4 cm, 180°)
IAEB	Cockcroft-Walton 600 kV, made in China	0.200	Open	15 cm 45° (IAEB1); 0° (IAEB2)	TE-transmission chamber (5 cm, 0°); associated α particle
NIM	200 kV Voltage multiplier, made in China	0.200	Open	14.5 cm 0°	TE-transmission chamber (10 cm, 0°)

Table 4b . Neutron spectrum in local (d+T) neutron fields

LAB	Neutron spectrum
BIPM	Calculated average energy: 14.65 MeV , spread 0.100 MeV
TNO	Theoretical spectrum is given. Average energy: 15 MeV
NPL	Mean energy: 14.65 MeV , 0.3 % dose below 4 MeV
PTB	Theoretical spectrum is given. Peak neutron energy: 15 MeV
ETL	Calculated neutron and gamma spectra are given. Peak neutron energy: 14.6 MeV , total spread 0.340 MeV
NBS	There are two groups of neutrons: - first group due to (d+T) : mean energy 17.5 MeV , spread 0.45 MeV , A-150 kerma 57.2 % - second group due to (d+D): mean energy 4.7 MeV , A-150 kerma 42.8 %
IAEB	45° : mean energy 14.57 MeV (IAEB1) 0° : mean energy 14.76 MeV (IAEB2)
NIM	-

Table 5. Ratios of the responses, R(gas)/R(dry air), for BIPM ionization chambers, measured in local photon calibration fields

	R(TE)/R(dry air) for TE chamber		R(Ar)/R(dry air) for Mg chamber	
LAB	Value	LAB/BIPM	Value	LAB/BIPM
BIPM	1.170	1.000	1.435	1.000
TNO	1.169	0.999	1.477	1.029
NPL	1.167	0.997	1.464	1.020
PTB	1.169	0.999	1.452	1.012
ETL	1.162	0.993	1.433	0.999
NBS	1.166	0.997	1.446	1.008
IAEB	1.161	0.992	1.460	1.017
NIM	1.165	0.996	1.478	1.030

Table 6. BIPM TE chambers calibrated in a ^{60}Co or ^{137}Cs photon field

LAB*	Ch. 266 α_c(Gy/C) / 10^7	Ch. 199 α_c(Gy/C) / 10^7	Ch. 250 α_c(Gy/C) / 10^7
BIPM	4.841 ± 0.029	4.612 ± 0.028	
TNO	4.826 ± 0.048	4.598 ± 0.046	-
BIPM	4.851 ± 0.029	4.616 ± 0.028	
NPL	4.886 ± 0.054	4.615 ± 0.051	-
BIPM	4.849 ± 0.029	4.616 ± 0.028	
PTB**	4.816 ± 0.082	4.554 ± 0.077	-
BIPM	4.866 ± 0.029	4.624 ± 0.028	
ETL	5.120 ± 0.051	4.853 ± 0.049	-
BIPM	4.858 ± 0.029	4.621 ± 0.028	
NBS**	4.810 ± 0.048	-	-
BIPM	4.869 ± 0.029	-	4.529 ± 0.027
IAEB	4.918 ± 0.067	-	4.579 ± 0.063
NIM	4.852 ± 0.040	-	4.512 ± 0.037
BIPM	4.849 ± 0.029	-	4.522 ± 0.027

* : all participants used ^{60}Co, except for TNO and NPL which used ^{137}Cs
** : the exposure standards are determined with the revised values for the stopping powers of electrons

Table 7. BIPM GM counter and Mg chamber calibrated in a ^{60}Co or ^{137}Cs photon field

LAB*	GM3 α_c(Gy.s^{-1}/count rate) / 10^{-9}	Ch. 139 α_c(Gy/C) / 10^7
BIPM	1.791 ± 0.013	3.876 ± 0.027
TNO	1.714 ± 0.103	3.695 ± 0.037
BIPM	1.797 ± 0.013	3.897 ± 0.027
NPL	1.937 ± 0.019	3.730 ± 0.041
BIPM	1.815 ± 0.013	3.879 ± 0.027
PTB**	1.832 ± 0.031	3.793 ± 0.072
BIPM	1.818 ± 0.013	3.881 ± 0.027
ETL	1.820 ± 0.018	3.942 ± 0.039
BIPM	1.807 ± 0.013	3.880 ± 0.027
NBS**	1.800 ± 0.018	3.838 N 0.038
BIPM	1.841 ± 0.013	3.880 ± 0.027
IAEB	1.829 ± 0.025	3.822 ± 0.052
NIM	1.817 ± 0.018	3.718 ± 0.030
BIPM	1.845 ± 0.013	3.885 ± 0.027

* : all participants used ^{60}Co, except for TNO and NPL which used ^{137}Cs
** : the exposure standards are determined with the revised values for the stopping powers of electrons

Table 8. Ratios of LAB-to-BIPM photon kerma calibration factors, $\alpha_c(LAB)/\alpha_c(BIPM)$, for BIPM dosimeters

LAB*		Ch. 266 (TE)	Ch. 199 (TE)	Ch. 250 (TE)	GM3	Ch. 139 (Mg)
TNO	a	0.9968	0.9970	-	0.9567	0.9533
	b	0.9958	0.9965	-	0.9551	0.9509
NPL	a	1.0071	0.9998	-	1.0775	0.9571
	b	1.0073	0.9998	-	1.0720	0.9593
PTB	a	1.0009	0.9942	-	1.0166	0.9854
	b	0.9991	0.9934	-	1.0160	0.9851
ETL	a	1.0522	1.0496	-	1.0011	1.0158
	b	1.0530	1.0499	-	1.0040	1.0158
NBS	a	0.9977	-	-	1.0033	0.9899
	b	0.9966	-	-	0.9940	0.9900
IAEB	a	1.0101	-	1.0110	0.9931	0.9850
	b	1.0121	-	1.0117	0.9919	0.9843
NIM	a	0.9965	-	0.9963	0.9867	0.9582
	b	0.9985	-	0.9970	0.9855	0.9575

Notes

* : all participants used ^{60}Co, except for TNO and NPL which used ^{137}Cs

a : with BIPM calibration values obtained before LAB measurements

b : with BIPM mean calibration values obtained before and after LAB measurements

Table 9. Correction factors determined by participants for TE and Mg chambers in calibrated photon fields

(A) Ch. 266 (TE)

LAB*	Wall (mm)	k_s	k_p	k_w	k_{st}	k_l	kf
BIPM	4	1.0013	1.0000	1.0141	1.0000	1.0000	1.0000
TNO	3	1.0000	1.0000	1.0150	1.0000	1.0000	1.0000
NPL	4	1.0040	1.0000	1.0200	1.0000	1.0000	1.0000
PTB	4	1.0020	1.0010	1.0142	1.0000	1.0000	1.0000
ETL	4	1.0000	1.0000	1.0104	0.9993	1.0000	0.9991
NBS	2	1.0020	1.0000	1.0070	1.0000	1.0000	1.0000
IAEB1	4	1.0020	1.0000	1.0210	1.0000	1.0000	1.0000
IAEB2	4	1.0020	1.0000	1.0210	1.0000	1.0000	1.0000
NIM	4	1.0000	1.0000	1.0188	1.0000	1.0000	1.0000

(B) Ch. 199 (TE) or ch. 250 (TE) **

LAB*	Wall (mm)	k_s	k_p	k_w	k_{st}	k_l	kf
BIPM	4	1.0020	1.0000	1.0150	1.0000	1.0000	1.0000
TNO	3	1.0000	1.0000	1.0130	1.0000	1.0000	1.0000
NPL	4	1.0040	1.0000	1.0200	1.0000	1.0000	1.0000
PTB	4	1.0020	1.0010	1.0142	1.0000	1.0000	1.0000
ETL	4	1.0000	1.0000	1.0145	0.9993	1.0000	0.9991
BIPM	4	1.0017	1.0000	1.0141	1.0000	1.0000	1.0000
IAEB1	4	1.0020	1.0010	1.0190	1.0000	1.0000	1.0000
IAEB2	4	1.0020	1.0010	1.0190	1.0000	1.0000	1.0000
NIM	4	1.0000	1.0000	1.0181	1.0000	1.0000	1.0000

(C) Ch. 139 (Mg)

LAB*	Wall (mm)	k_s	k_p	k_w	k_{st}	k_l	kf
BIPM	3	1.0020	1.0000	1.0141	1.0000	1.0000	1.0000
TNO	4	1.0000	1.0000	1.0240	1.0000	1.0000	1.0000
NPL	4	1.0040	1.0000	1.0220	1.0000	1.0000	1.0000
PTB	3	1.0000	0.9920	1.0173	1.0000	0.9990	1.0000
ETL	3	1.0000	1.0000	1.0147	0.9992	1.0000	0.9982
NBS	2	1.0030	1.0000	1.0090	1.0000	1.0000	1.0000
IAEB1	3	1.0030	0.9940	1.0160	1.0000	1.0000	1.0000
IAEB2	3	1.0030	0.9940	1.0160	1.0000	1.0000	1.0000
NIM	3	1.0000	1.0000	1.0148	1.0000	1.0000	1.0000

* : all participants used ^{60}Co, except for TNO and NPL which used ^{137}Cs

** : all participants used ch. 199, except for IAEB and NIM which used ch. 250

Table 10. Normalized correction factors chosen for all participants in photon calibration measurements

(A) Ch. 266 (TE)

LAB*	Wall (mm)	k_s	k_p	k_w	k_{st}	k_1	kf
BIPM	4	1.0020	1.0000	1.0140	1.0000	1.0000	1.0000
TNO	3	1.0020	1.0000	1.0135	1.0000	1.0000	1.0000
NPL	4	1.0020	1.0000	1.0180	1.0000	1.0000	1.0000
PTB	4	1.0020	1.0010	1.0140	1.0000	1.0000	1.0000
ETL	4	1.0020	1.0000	1.0140	1.0000	1.0000	1.0000
NBS	2	1.0020	1.0000	1.0070	1.0000	1.0000	1.0000
IAEB1	4	1.0020	1.0000	1.0140	1.0000	1.0000	1.0000
IAEB2	4	1.0020	1.0000	1.0140	1.0000	1.0000	1.0000
NIM	4	1.0020	1.0000	1.0140	1.0000	1.0000	1.0000

(B) Ch. 199 (TE) or ch. 250 (TE) **

LAB*	Wall (mm)	k_s	k_p	k_w	k_{st}	k_1	kf
BIPM	4	1.0020	1.0000	1.0140	1.0000	1.0000	1.0000
TNO	3	1.0020	1.0000	1.0135	1.0000	1.0000	1.0000
NPL	4	1.0020	1.0000	1.0180	1.0000	1.0000	1.0000
PTB	4	1.0020	1.0010	1.0140	1.0000	1.0000	1.0000
ETL	4	1.0020	1.0000	1.0140	1.0000	1.0000	1.0000
BIPM	4	1.0020	1.0000	1.0140	1.0000	1.0000	1.0000
IAEB1	4	1.0020	1.0000	1.0140	1.0000	1.0000	1.0000
IAEB2	4	1.0020	1.0000	1.0140	1.0000	1.0000	1.0000
NIM	4	1.0020	1.0000	1.0140	1.0000	1.0000	1.0000

(C) Ch. 139 (Mg)

LAB*	Wall (mm)	k_s	k_p	k_w	k_{st}	k_1	kf
BIPM	3	1.0020	1.0000	1.0135	1.0000	1.0000	1.0000
TNO	4	1.0020	1.0000	1.0220	1.0000	1.0000	1.0000
NPL	4	1.0020	1.0000	1.0220	1.0000	1.0000	1.0000
PTB	3	1.0020	0.9920	1.0135	1.0000	0.9990	1.0000
ETL	3	1.0020	1.0000	1.0135	1.0000	1.0000	1.0000
NBS	2	1.0020	1.0000	1.0090	1.0000	1.0000	1.0000
IAEB1	3	1.0020	1.0000	1.0135	1.0000	1.0000	1.0000
IAEB2	3	1.0020	1.0000	1.0135	1.0000	1.0000	1.0000
NIM	3	1.0020	1.0000	1.0135	1.0000	1.0000	1.0000

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* : all participants used ^{60}Co, except for TNO and NPL which used ^{137}Cs

** : all participants used ch. 199, except for IAEB and NIM which used ch. 250

Table 11. Ratios of α_c(LAB) / α_c(BIPM), with normalized correction factors used by all participants

LAB*		Ch. 266 (TE)	Ch. 199 (TE)	Ch. 250 (TE)	Ch. 139 (Mg)
TNO	a	0.9969	0.9935	-	0.9527
	b	0.9959	0.9930	-	0.9503
NPL	a	1.0117	1.0028	-	0.9585
	b	1.0119	1.0027	-	0.9606
PTB	a	0.9996	0.9914	-	0.9844
	b	0.9978	0.9906	-	0.9842
ETL	a	1.0453	1.0453	-	1.0135
	b	1.0461	1.0456	-	1.0136
NBS	a	0.9983	-	-	0.9903
	b	0.9972	-	-	0.9904
IAEB	a	1.0120	-	1.0116	0.9775
	b	1.0141	-	1.0124	0.9768
NIM	a	0.9999	-	0.9985	0.9569
	b	1.0019	-	0.9993	0.9562

Notes

* : all participants used ^{60}Co, except for TNO and NPL which used ^{137}Cs

a : with BIPM calibr. values obtained before LAB measurements

b : with BIPM mean calibr. values obtained before and after LAB measurements

Table 12. Values of R'_T determined by participants for BIPM TE chambers

LAB	R'_T for Ch. 266 Value (Gy/um)	LAB/BIPM	R'_T for Ch. 199 or 250 * Value (Gy/um)	LAB/BIPM	R'_T Mean value Value (Gy/um)	LAB/BIPM
TNO	5.274×10^{-4}	0.9907	5.399×10^{-4}	0.9888	5.336×10^{-4}	0.9896
NPL	5.930×10^{3}	1.0037	5.900×10^{3}	0.9973	5.915×10^{3}	1.0005
PTB	8.174×10^{-9}	0.9967	8.145×10^{-9}	0.9918	8.159×10^{-9}	0.9942
ETL	3.648×10^{-8}	1.0392	3.661×10^{-8}	1.0442	3.655×10^{-8}	1.0419
NBS	2.292×10^{-5}	0.9909	-	-	2.292×10^{-5}	0.9909
IAEB1	5.010×10^{-5}	1.0108	5.006×10^{-5}	1.0153	5.008×10^{-5}	1.0130
IAEB2	5.523×10^{-5}	1.0108	5.548×10^{-5}	1.0153	5.535×10^{-5}	1.0130
NIM	2.571×10^{-5}	0.9992	2.566×10^{-5}	0.9995	2.569×10^{-5}	0.9994

Notes
* : all participants used ch. 199, except for IAEB and NIM which used ch. 250
um = unit of monitor

Table 13. Values of R'_U determined by participants for BIPM GM counter and Mg chamber

LAB	R'_U for GM3 Value (Gy/um)	LAB/BIPM	R'_U for Ch. 139 (Mg) Value (Gy/um)	LAB/BIPM
TNO	0.519×10^{-4}	0.9558	1.108×10^{-4}	0.9398
NPL	0.260×10^{3}	1.0788	1.100×10^{3}	0.9607
PTB	0.3133×10^{-9}	1.0165	1.503×10^{-9}	0.9862
ETL	0.1445×10^{-8}	1.0007	6.520×10^{-9}	0.9995
NBS	0.1649×10^{-5}	1.0037	2.838×10^{-6}	0.9954
IAEB1	0.2200×10^{-5}	0.9932	9.239×10^{-6}	0.9840
IAEB2	0.2280×10^{-5}	0.9930	1.010×10^{-5}	0.9840
NIM	0.1851×10^{-5}	0.9867	5.328×10^{-6}	0.9562

um = unit of monitor

Table 14. Correction factors determined by participants for BIPM TE and Mg chambers in neutron fields

(A) Ch. 266 (TE)

LAB	Wall (mm)	k_s	k_P	k_w	k_{st}	k_l	kf
BIPM	3	1.0062	1.0000	1.0100	1.0000	1.0000	1.0000
TNO	3	1.0010	1.0000	1.0090	1.0000	1.0000	1.0000
NPL	5	1.0040	1.0000	1.0160	1.0000	1.0000	1.0000
PTB	3	1.0040	0.9870	1.0080	1.0000	1.0000	1.0000
ETL	3	1.0000	1.0000	1.0037	1.0000	1.0000	0.9991
NBS	2	1.0020	1.0000	1.0040	1.0000	1.0000	1.0000
IAEB1	3	1.0020	1.0010	1.0150	1.0000	1.0000	1.0000
IAEB2	3	1.0020	1.0010	1.0150	1.0000	1.0000	1.0000
NIM	3	1.0000	1.0000	1.0190	1.0000	1.0000	1.0000

(B) Ch. 199 (TE) or ch. 250 (TE) *

LAB	Wall (mm)	k_s	k_P	k_w	k_{st}	k_l	kf
BIPM	3	1.0041	1.0000	1.0110	1.0000	1.0000	1.0000
TNO	3	1.0010	1.0000	1.0060	1.0000	1.0000	1.0000
NPL	5	1.0040	1.0000	1.0160	1.0000	1.0000	1.0000
PTB	3	1.0040	0.9880	1.0080	1.0000	1.0000	1.0000
ETL	3	1.0000	1.0000	1.0092	1.0000	1.0000	0.9991
BIPM	3	1.0027	1.0000	1.0130	1.0000	1.0000	1.0000
IAEB1	3	1.0050	1.0040	1.0150	1.0000	1.0000	1.0000
IAEB2	3	1.0050	1.0040	1.0150	1.0000	1.0000	1.0000
NIM	3	1.0000	1.0000	1.0190	1.0000	1.0000	1.0000

(C) Ch. 139 (Mg)

LAB	Wall (mm)	k_s	k_P	k_w	k_{st}	k_l	kf
BIPM	4	1.0020	1.0000	1.0200	1.0000	1.0000	1.0000
TNO	4	1.0000	1.0000	1.0080	1.0000	1.0000	1.0000
NPL	4	1.0040	1.0000	1.0160	1.0000	1.0000	1.0000
PTB	3	1.0000	0.9420	1.0183	1.0000	0.9990	1.0000
ETL	3	1.0000	1.0000	0.9989	1.0000	1.0000	0.9982
NBS	2	1.0110	1.0000	1.0010	1.0070	1.0000	1.0000
IAEB1	2	1.0090	0.9950	1.0020	1.0000	1.0000	1.0000
IAEB2	2	1.0090	0.9950	1.0020	1.0000	1.0000	1.0000
NIM	3	1.0000	1.0000	1.0150	1.0000	1.0000	1.0000

* : all participants used ch. 199, except for IAEB and NIM which used ch. 250

Table 15. Normalized correction factors chosen for all participants in neutron fields

(A) Ch. 266 (TE)

LAB	Wall (mm)	k_s	k_p	k_w	k_{st}	k_1	kf
BIPM	3	1.0040	1.0000	1.0090	1.0000	1.0000	1.0000
TNO	3	1.0040	1.0000	1.0090	1.0000	1.0000	1.0000
NPL	5	1.0040	1.0000	1.0150	1.0000	1.0000	1.0000
PTB	3	1.0040	0.9870	1.0090	1.0000	1.0000	1.0000
ETL	3	1.0040	1.0000	1.0090	1.0000	1.0000	1.0000
NBS	2	1.0040	1.0000	1.0060	1.0000	1.0000	1.0000
IAEB1	3	1.0040	1.0010	1.0090	1.0000	1.0000	1.0000
IAEB2	3	1.0040	1.0010	1.0090	1.0000	1.0000	1.0000
NIM	3	1.0040	1.0000	1.0090	1.0000	1.0000	1.0000

(B) Ch. 199 (TE) or ch. 250 (TE) *

LAB	Wall (mm)	k_s	k_p	k_w	k_{st}	k_1	kf
BIPM	3	1.0040	1.0000	1.0090	1.0000	1.0000	1.0000
TNO	3	1.0040	1.0000	1.0090	1.0000	1.0000	1.0000
NPL	5	1.0040	1.0000	1.0150	1.0000	1.0000	1.0000
PTB	3	1.0040	0.9880	1.0090	1.0000	1.0000	1.0000
ETL	3	1.0040	1.0000	1.0090	1.0000	1.0000	1.0000
BIPM	3	1.0040	1.0000	1.0090	1.0000	1.0000	1.0000
IAEB1	3	1.0040	1.0040	1.0090	1.0000	1.0000	1.0000
IAEB2	3	1.0040	1.0040	1.0090	1.0000	1.0000	1.0000
NIM	3	1.0040	1.0000	1.0090	1.0000	1.0000	1.0000

(C) Ch. 139 (Mg)

LAB	Wall (mm)	k_s	k_p	k_w	k_{st}	k_1	kf
BIPM	4	1.0020	1.0000	1.0200	1.0000	1.0000	1.0000
TNO	4	1.0020	1.0000	1.0200	1.0000	1.0000	1.0000
NPL	4	1.0020	1.0000	1.0200	1.0000	1.0000	1.0000
PTB	3	1.0020	0.9420	1.0150	1.0000	0.9990	1.0000
ETL	3	1.0020	1.0000	1.0150	1.0000	1.0000	1.0000
NBS	2	1.0020	1.0000	1.0100	1.0000	1.0000	1.0000
IAEB1	2	1.0020	0.9950	1.0100	1.0000	1.0000	1.0000
IAEB2	2	1.0020	0.9950	1.0100	1.0000	1.0000	1.0000
NIM	3	1.0020	1.0000	1.0150	1.0000	1.0000	1.0000

* : all participants used ch. 199, except for IAEB and NIM which used ch. 250

Table 16. Ratios of $R'_\tau(LAB)/R'_\tau(BIPM)$ or $R'_\upsilon(LAB)/R'_\upsilon(BIPM)$, with normalized correction factors used by all participants

LAB	$R'_\tau(LAB)/R'_\tau(BIPM)$ Ch. 266 (TE)	Ch. 199 (TE)	Ch. 250 (TE)	$R'_\upsilon(LAB)/R'_\upsilon(BIPM)$ Ch. 139 (Mg)
TNO	0.9969	0.9935	-	0.9527
NPL	1.0117	1.0028	-	0.9585
PTB	0.9996	0.9914	-	0.9844
ETL	1.0453	1.0453	-	1.0135
NBS	0.9983	-	-	0.9903
IAEB	1.0120	-	1.0116	0.9775
NIM	0.9999	-	0.9985	0.9569

Table 17. Kerma values, for A-150 plastic, determined with BIPM dosimeters

(A) Combination (TE chamber + GM3)

LAB		R'_T*	R'_U	k_T	k_U	K_N	K_G	K_{tot}
TNO	a	5.336×10^{-4}	0.519×10^{-4}	0.9510	0.0260	5.208×10^{-4}	0.384×10^{-4}	5.592×10^{-4}
NPL	a	5.915×10^{3}	0.260×10^{3}	0.9510	0.0260	6.115×10^{3}	0.100×10^{3}	6.215×10^{3}
PTB	a	8.159×10^{-9}	0.313×10^{-9}	0.9420	0.0241	8.547×10^{-9}	0.107×10^{-9}	8.655×10^{-9}
ETL	a	3.655×10^{-8}	0.145×10^{-8}	0.9550	0.0241	3.771×10^{-8}	0.536×10^{-9}	3.825×10^{-8}
NBS	a	2.292×10^{-5}	0.165×10^{-5}	0.9529	0.0195	2.279×10^{-5}	0.120×10^{-5}	2.399×10^{-5}
IAEB1	a	5.008×10^{-5}	0.220×10^{-5}	0.9490	0.0241	5.177×10^{-5}	0.095×10^{-5}	5.272×10^{-5}
IAEB2	a	5.535×10^{-5}	0.228×10^{-5}	0.9490	0.0241	5.738×10^{-5}	0.090×10^{-5}	5.828×10^{-5}
NIM	a	2.569×10^{-5}	0.185×10^{-5}	0.9550	0.0241	2.560×10^{-5}	0.123×10^{-5}	2.684×10^{-5}
TNO	b	0.9896	0.9558	1.000	1.0788	0.9954	0.9201	0.9899
NPL	b	1.0005	1.0788	1.000	1.0788	0.9992	1.0802	1.0004
PTB	b	0.9942	1.0165	1.000	1.0000	0.9933	1.0644	0.9941
ETL	b	1.0419	1.0007	1.000	1.0000	1.0437	0.9354	1.0420
NBS	b	0.9909	1.0037	1.000	1.0000	0.9899	1.0088	0.9909
IAEB1	b	1.0130	0.9932	1.000	1.0000	1.0139	0.9684	1.0130
IAEB2	b	1.0130	0.9930	1.000	1.0000	1.0139	0.9615	1.0130
NIM	b	0.9994	0.9867	1.000	1.0000	1.0004	0.9799	0.9995
Mean		1.0042	-	-	-	1.0051	0.9934	1.0043
S.D.		0.0184	-	-	-	0.0187	0.0613	0.0184
** Mean		0.9979	-	-	-	0.9987	1.0031	0.9980
** S.D.		0.0086	-	-	-	0.0084	0.0610	0.0085

Notes

* : the values of R'_T are the mean values obtained with the two TE chambers used

a : values obtained with LAB calibration factors ; R'_T, R'_U, K_N, K_G and K_{tot} are given in Gy/unit of monitor

b : values obtained with LAB calibration factors relative to those obtained with BIPM calibration factors

Mean : mean values calculated with the IAEB values taken from the average values of IAEB1 and IAEB2

S.D. : one standard deviation

** : ETL values excluded

Table 17 (continued). Kerma values, for A-150 plastic, determined with BIPM dosimeters

(B) Combination (TE chamber + Mg chamber)

LAB		R'_T*	R'_U	k_T	k_U	K_N	K_G	K_{tot}
TNO	a	5.336×10^{-4}	1.108×10^{-4}	0.9510	0.1600	5.345×10^{-4}	0.253×10^{-4}	5.598×10^{-4}
NPL	a	5.915×10^{3}	1.100×10^{3}	0.9510	0.1570	6.075×10^{3}	0.140×10^{3}	6.215×10^{3}
PTB	a	8.159×10^{-9}	1.503×10^{-9}	0.9420	0.1620	8.533×10^{-9}	0.121×10^{-9}	8.654×10^{-9}
ETL	a	3.655×10^{-8}	0.652×10^{-8}	0.9550	0.1620	3.787×10^{-8}	0.385×10^{-9}	3.825×10^{-8}
NBS	a	2.292×10^{-5}	0.284×10^{-5}	0.9529	0.1400	2.470×10^{-5}	-0.62×10^{-6}	2.408×10^{-5}
IAEB1	a	5.008×10^{-5}	0.924×10^{-5}	0.9490	0.1620	5.190×10^{-5}	0.083×10^{-5}	5.273×10^{-5}
IAEB2	a	5.535×10^{-5}	1.011×10^{-5}	0.9490	0.1620	5.749×10^{-5}	0.079×10^{-5}	5.828×10^{-5}
NIM	a	2.569×10^{-5}	0.533×10^{-5}	0.9550	0.1620	2.567×10^{-5}	0.117×10^{-5}	2.684×10^{-5}
TNO	b	0.9896	0.9398	1.000	0.9877	1.0010	0.8051	0.9901
NPL	b	1.0005	0.9607	1.000	0.9691	1.0037	0.8899	1.0007
PTB	b	0.9942	0.9862	1.000	1.0000	0.9960	0.8868	0.9942
ETL	b	1.0419	0.9995	1.000	1.0000	1.0516	0.5590	1.0423
NBS	b	0.9909	0.9954	1.000	1.0000	0.9903	0.9674	0.9909
IAEB1	b	1.0130	0.9840	1.000	1.0000	1.0198	0.7237	1.0133
IAEB2	b	1.0130	0.9840	1.000	1.0000	1.0197	0.6979	1.0133
NIM	b	0.9994	0.9562	1.000	1.0000	1.0114	0.8008	0.9999
Mean		1.0042	-	-	-	1.0105	0.8028	1.0043
S.D.		0.0184	-	-	-	0.0205	0.1352	0.0184
** Mean		0.9979	-	-	-	1.0037	0.8435	0.9980
** S.D.		0.0086	-	-	-	0.0106	0.0898	0.0086

Notes

* : the values of R'_T are the mean values obtained with the two TE chambers used

a : values obtained with LAB calibration factors ; R'_T, R'_U, K_N, K_G and K_{tot} are given in Gy/unit of monitor

b : values obtained with LAB calibration factors relative to those obtained with BIPM calibration factors

Mean : mean values calculated with the IAEB values taken from the average values of IAEB1 and IAEB2

S.D. : one standard deviation

** : ETL values excluded

Table 18. Local dosimeters used in the comparison

LAB	TE chamber	GM counter	Mg chamber
TNO	One T2 (Exradin)	One GM (Philips 18529)	One MG2 (Exradin)
NPL	One T2	Two GM : ZP1311 ZP1300	One MG2
PTB	One T2	One GM (ZP1100)	One MG2
ETL	One T2	One GM	One MG2
NBS	Two T2 and two RTG (FWT)	One GM	Two MG2 and one RMG (FWT)
IAEB	One TE (China)	One GM	One MG (China)
NIM	One TE (China)	One GM	-

Table 19. Values of R'_T, R'_U and K_a/K_{tot} obtained with local dosimeters

LAB	Combination of dosimeters	R'_T (Gy/um)	R'_U (Gy/um)	k_U	K_a/K_{tot} (%)
TNO	T2 + GM	5.3330×10^{-4}	0.4480×10^{-4}	0.018	6.3
	T2 + MG2		1.1160×10^{-4}	0.150	5.8
NPL	T2 + GM	0.5915×10^{4}	0.0240×10^{4}	0.027	1.2
	T2 + MG2		0.1135×10^{4}	0.171	1.4
PTB	T2 + GM	0.8158×10^{-8}	0.3238×10^{-9}	0.025	1.3
	T2 + MG2		0.1518×10^{-8}	0.165	1.2
ETL	T2 + GM	3.6650×10^{-8}	0.1067×10^{-8}	0.019	0.9
	T2 + MG2		0.6570×10^{-8}	0.159	1.5
NBS	T2 + GM	0.2234×10^{-4}	0.1253×10^{-5}	0.0226	3.2
	T2 + MG2		0.2886×10^{-5}	0.140	-2.0
	T2 + RMG*		0.2606×10^{-5}	0.140	-3.4
IAEB1	TE + GM	4.9618×10^{-5}	0.1663×10^{-5}	0.017	1.5
	TE + Mg		0.9249×10^{-5}	0.168	1.1
IAEB2	TE + GM	5.5271×10^{-5}	0.1819×10^{-5}	0.017	1.5
	TE + Mg		1.0604×10^{-5}	0.168	1.7
NIM	TE + GM	2.5670×10^{-5}	0.1566×10^{-5}	0.017	4.2

Notes
um = unit of monitor
* : the results obtained with the RMG(FWT) type Mg chambers are not included in the analysis of the results of comparison

Table 20. Kerma values, for A-150 plastic, obtained with local dosimeters relative to those obtained with BIPM dosimeters which are calibrated at BIPM

(A) Combination (TE chamber + GM counter)

LAB	R'_T*	K_N	K_G	K_{tot}
TNO	0.9891 ±0.0208	1.0008 ±0.0237	0.8485 ±0.0655	0.9896 ±0.0208
NPL	1.0005 ±0.0150	1.0038 ±0.0160	0.7929 ±0.1734	1.0007 ±0.0150
PTB	0.9940 ±0.0214	0.9928 ±0.0225	1.0933 ±0.2787	0.9940 ±0.0214
ETL	1.0448 ±0.0198	1.0521 ±0.0210	0.6014 ±0.2099	1.0451 ±0.0198
NBS	0.9658 ±0.0303	0.9847 ±0.0329	0.6203 ±0.0595	0.9667 ±0.0303
IAEB1	1.0036 ±0.0169	1.0078 ±0.0178	0.8007 ±0.1013	1.0038 ±0.0169
IAEB2	1.0115 ±0.0170	1.0134 ±0.0178	0.9056 ±0.1288	1.0116 ±0.0170
NIM	0.9988 ±0.0129	1.0041 ±0.0142	0.8967 ±0.0475	0.9991 ±0.0129
Mean	1.0001	1.0070	0.8152	1.0004
S.D.	0.0238	0.0216	0.1687	0.0236
** Mean	0.9926	0.9995	0.8508	0.9930
** S.D.	0.0145	0.0093	0.1532	0.0143

(B) Combination (TE chamber + Mg chamber)

LAB	R'_T*	K_N	K_G	K_{tot}
TNO	0.9891 ±0.0208	0.9860 ±0.0376	1.0393 ±0.4443	0.9889 ±0.0208
NPL	1.0005 ±0.0150	1.0143 ±0.0234	0.5239 ±0.3885	1.0012 ±0.0150
PTB	0.9940 ±0.0214	0.9974 ±0.0303	0.7939 ±0.8419	0.9942 ±0.0214
ETL	1.0448 ±0.0198	1.0494 ±0.0340	0.8148 ±1.159	1.0450 ±0.0198
NBS	0.9658 ±0.0303	0.9593 ±0.0486	0.7240 ±1.267	0.9655 ±0.0302
IAEB1	1.0036 ±0.0169	1.0157 ±0.0248	0.4936 ±0.4351	1.0042 ±0.0169
IAEB2	1.0115 ±0.0170	1.0143 ±0.0248	0.8782 ±0.5964	1.0117 ±0.0170
Mean	1.0003	1.0036	0.7636	1.0004
S.D.	0.0260	0.0305	0.1701	0.0262
** Mean	0.9914	0.9944	0.7534	0.9915
** S.D.	0.0159	0.0231	0.1881	0.0162

Notes

* : the values of R'_T are the mean values obtained with the two TE chambers used

Mean : mean values calculated with the IAEB values taken from the average values of IAEB1 and IAEB2

S.D. : one standard deviation

** : ETL values excluded

Table 21. Kerma values, for A-150 plastic, obtained with local dosimeters relative to those obtained with BIPM dosimeters which are calibrated by participants

(A) Combination (TE chamber + GM counter)

LAB	R'_T*	K_N	K_G	K_{tot}
TNO	0.9994 ±0.0255	1.0054 ±0.0296	0.9222 ±0.1097	0.9997 ±0.0255
NPL	1.0000 ±0.0170	1.0046 ±0.0181	0.7340 ±0.1613	1.0002 ±0.0170
PTB	0.9999 ±0.0277	0.9995 ±0.0290	1.0271 ±0.2276	0.9999 ±0.0277
ETL	1.0027 ±0.0237	1.0081 ±0.0249	0.6429 ±0.2300	1.0030 ±0.0237
NBS	0.9747 ±0.0414	0.9947 ±0.0453	0.6149 ±0.0660	0.9756 ±0.0414
IAEB1	0.9908 ±0.0199	0.9940 ±0.0209	0.8268 ±0.1109	0.9910 ±0.0199
IAEB2	0.9986 ±0.0201	0.9995 ±0.0210	0.9419 ±0.1431	0.9986 ±0.0201
NIM	0.9994 ±0.0131	1.0037 ±0.0147	0.9151 ±0.0756	0.9996 ±0.0131
Mean	0.9958	1.0018	0.8201	0.9961
S.D.	0.0096	0.0049	0.1567	0.0094

(B) Combination (TE chamber + Mg chamber)

LAB	R'_T*	K_N	K_G	K_{tot}
TNO	0.9994 ±0.0255	0.9849 ±0.0485	1.2909 ±0.8768	0.9988 ±0.0255
NPL	1.0000 ±0.0170	1.0105 ±0.0250	0.5887 ±0.4448	1.0005 ±0.0170
PTB	0.9999 ±0.0277	1.0014 ±0.0374	0.8952 ±1.046	1.0000 ±0.0277
ETL	1.0027 ±0.0237	0.9979 ±0.0367	1.4577 ±2.439	1.0025 ±0.0237
NBS	0.9747 ±0.0414	0.9687 ±0.0669	0.7484 ±1.629	0.9744 ±0.0413
IAEB1	0.9908 ±0.0199	0.9960 ±0.0277	0.6821 ±0.6709	0.9911 ±0.0199
IAEB2	0.9986 ±0.0201	0.9948 ±0.0277	1.2583 ±1.078	0.9984 ±0.0200
Mean	0.9952	0.9931	0.9919	0.9952
S.D.	0.0104	0.0146	0.3280	0.0105

Notes

* : the values of R'_T are the mean values obtained with the two TE chambers used

Mean : mean values calculated with the IAEB values taken from the average values of IAEB1 and IAEB2

S.D. : one standard deviation

Table 22. Values of K_G/K_{tot} , in the local (neutron + gamma) mixed fields, obtained with local and BIPM dosimeters

(A) Combination (TE chamber + GM counter)

LAB	Local dosimeters K_G/K_{tot} (%) (F_1)	BIPM dosimeters: Calibrated at BIPM K_G/K_{tot} (%) (F_2)	BIPM dosimeters: Calibrated at LAB K_G/K_{tot} (%) (F_3)	Differences (%) (F_1-F_2)	Differences (%) (F_1-F_3)
TNO	6.3	7.4	6.9	-1.1	-0.6
NPL	1.2	1.5	1.6	-0.3	-0.4
PTB	1.3	1.2	1.2	+0.1	+0.1
ETL	0.9	1.6	1.4	-0.7	-0.5
NBS	3.2	4.9	5.0	-1.7	-1.8
IAEB1	1.5	1.9	1.8	-0.4	-0.3
IAEB2	1.5	1.6	1.5	-0.1	0.0
NIM	4.2	4.7	4.6	-0.5	-0.4

(B) Combination (TE chamber + Mg chamber)

LAB	Local dosimeters K_G/K_{tot} (%) (F_1)	BIPM dosimeters: Calibrated at BIPM K_G/K_{tot} (%) (F_2)	BIPM dosimeters: Calibrated at LAB K_G/K_{tot} (%) (F_3)	Differences (%) (F_1-F_2)	Differences (%) (F_1-F_3)
TNO	5.8	5.5	4.5	+0.3	+1.3
NPL	1.4	2.7	2.3	-1.3	-0.9
PTB	1.2	1.6	1.4	-0.4	-0.2
ETL	1.5	1.9	1.0	-0.4	+0.5
NBS	-2.0	-2.6	-2.6	-	-
IAEB1	1.1	2.2	1.6	-1.1	-0.5
IAEB2	1.7	2.0	1.4	-0.3	+0.3

Table 23. Combined relative uncertainties for α_c, R'_T, R'_U and k_U

(A) BIPM dosimeters

LAB	TE chamber uncertainties (%) α_c	TE chamber uncertainties (%) R'_T	GM counter uncertainties (%) α_c	GM counter uncertainties (%) R'_U	GM counter uncertainties (%) k_U	Mg chamber uncertainties (%) α_c	Mg chamber uncertainties (%) R'_U	Mg chamber uncertainties (%) k_U
BIPM	0.6	0.9	0.7	0.7	7.8	0.7	1.4	4.5
TNO	1.0	1.7	6.0	6.1	11.1	1.0	1.7	13.3
NPL	1.1	1.2	1.0	1.2	7.7	1.1	1.2	4.5
PTB	1.7	1.96	1.7	1.73	4.5	1.9	2.42	4.5
ETL	1.0	1.67	1.0	1.56	7.8	1.0	2.04	4.5
NBS	1.0	3.0	1.0	3.0	10.0	1.0	3.0	20.0
IAEB	1.37	1.42	1.34	1.38	5.9	1.37	1.38	4.5
NIM	0.82	0.93	0.82	0.93	7.8	0.82	0.93	4.5

(B) Local dosimeters

LAB	TE chamber uncertainties (%) α_c	TE chamber uncertainties (%) R'_T	GM counter uncertainties (%) α_c	GM counter uncertainties (%) R'_U	GM counter uncertainties (%) k_U	Mg chamber uncertainties (%) α_c	Mg chamber uncertainties (%) R'_U	Mg chamber uncertainties (%) k_U
TNO	1.2	1.9	5.0	5.1	11.1	1.2	1.9	13.3
NPL	1.1	1.2	1.0	1.2	7.4	1.1	1.2	4.1
PTB	1.7	1.96	1.9	1.92	9.0	1.9	2.36	4.5
ETL	1.0	1.67	1.0	1.56	15.0	1.0	2.04	10.0
NBS	1.0	3.0	1.0	3.0	10.0	1.0	3.0	20.0
IAEB	1.37	1.42	1.34	1.38	5.9	1.37	1.38	3.6
NIM	0.82	0.93	0.82	0.93	17.6	-	-	-

Note : the uncertainties given in these tables are expressed in one standard deviation

References

[1] J.J. Broerse, B.J. Mijnheer and J.R. Williams, European protocol for neutron dosimetry external beam therapy, Brit. J. of Radiology 54, 882 (1981)

[2] International Commission on Radiation Units and Measurements, Neutron Dosimetry for Biology and Medicine, ICRU Report 26 (International Commission on Radiation Units and Measurements, Bethesda, Maryland)

[3] B.J. Mijnheer and J.R. Williams, Determination of absorbed dose and kerma in a neutron field from measurements with a tissue-equivalent ionisation chamber, Phys. Med. Biol. 26, 57 (1981)

(June 1988)