Comparison of primary absorbed dose to water standards in the medium-energy x-ray range

Technical Protocol

Pilot laboratory:
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Contents

1. Object and participants

The objective of this project is to carry out a comparison of primary measurement standards of absorbed dose to water for the medium-energy x-ray range. The prospective participants are listed in Table 1. Three of the participants (VSL B.V., PTB, LNE-LNHB) have operating primary standards based on water calorimeters as published in references [1 – 3]. The remaining two participants are developing new primary standards based on a water-graphite calorimeter (ENEA) and a graphite extrapolation chamber (MKEH). According to the schedule of deliverables the newly developed primary standards should be available by the end of May 2014.

Table 1: Participants and contact persons

Participant	Institute	Country	Contact person	E-mail of contact person
1	PTB	Germany	Ludwig Büermann	ludwig.bueermann@ptb.de
2	LNE-LNHB	France	Benjamin Rapp	benjamin.rapp@cea
3	VSL B.V.	Netherlands	Leon de Prez	ldprez@vsl.nl
4	MKEH	Hungary	Gábor Machula	machulag@mkeh.hu
5	ENEA	Italy	Massimo Pinto	Massimo.pinto@enea.it

Note: Complete addresses are given in Appendix B.

Three waterproof farmer type chambers (see clause 2) will be used as transfer chambers. Each participant calibrates the transfer chambers under reference conditions as defined below (clause 4) in terms of air kerma free in air and absorbed dose to water in the depth of 2 g/cm^2. Additional charge measurements shall be made with the transfer chambers in a depth of 5 g/cm^2 (clause 4.3).

2 Transfer chambers

Three ionization chambers of the same type PTW TM30013 with a nominal volume of 0,6 cm^3 will be provided by PTB and used as transfer chambers. The chambers are manufactured by PTW. The chambers have a PTW-M type connector. An appropriate adapter to other connections will be provided by PTB. Participants are pleased to inform the pilot laboratory about their needs.

Table 2: Main technical data of the transfer chambers

Type:	TM30013, serial numbers 7463, 7484, 7485
Nominal sensitive volume:	0,6 cm^3
Chamber high voltage:	300 V
Leakage current:	$\leq \pm$4fA
Nominal response:	20 nC/Gy
Minimum air kerma rate:	0,2 mGy/s (yields about 4 pA)

3 Radiation qualities

The CCRI radiation qualities in the range from 100 kV to 250 kV (CCEMRI 1972, Ref. [8]) shall be used for the comparison. The PTB realisation of these qualities are shown in Table 3.

Table 3: Characteristics of the PTB reference radiation qualities

Radiation quality	100 kV	135 kV	180 kV	250 kV
Generating potential / kV	100	135	180	250
Additional Al filtration / mm	3.506	2.302	2.302	2.302
Additional Cu filtration / mm	-	0.222	0.512	1.590
Al HVL / mm	4.142	-	-	-
Cu HVL / mm	0.157	0.489	1.013	2.482
$(\mu/\rho)_{air}$ / cm^2 g^{-1}	0.287	0.196	0.168	0.143
$\dot{K}_{PTB}$ / mGy s^{-1}	0.50	0.50	0.50	0.50

4 Measurement procedure and reference conditions

4.1 Measurement procedure

Measurements free-in-air in the water phantom should not start before the chamber has equalized to the ambient temperature. After connection of the high voltage it is advisable to wait at least 1 hour until the measurements begin. The currents of the transfer chambers at the place of measurement should always be measured with and without the radiation beam. The signal to background ratio of the currents should not be less than 1000. The background current shall be subtracted from the signal current. A complete measurement should consist of at least 10 repeated single measurements and the mean value should be taken as the result. The relative percentage Type A standard uncertainty of the repeated measurements shall not exceed 0,1%.

The calibration coefficients of the transfer chambers shall be measured at both polarities and given in terms of air kerma or absorbed dose to water per unit charge in units of Gy/C referring to standard conditions of air temperature, pressure and relative humidity of T = 293,15 K, P = 101,325 kPa and h = 50 %. All measurements shall be performed in the same x-ray beam. The relative air humidity shall be between 20 % and 80 % during the calibrations otherwise a correction to h = 50 % should be applied. Participants do not need to apply any correction for the incomplete charge collection.

The transfer chambers shall be calibrated at the reference conditions listed in 4.2 and 4.3. Unfortunately, it was not possible to agree on exactly the same reference conditions at all participants' sites. However, it was confirmed that these differences should not cause significant differences in the calibration coefficients of the transfer chambers.

4.2 Reference conditions for the calibration in terms of absorbed dose to water

Dimensions of the water phantom	30 cm x 30 cm x 30 cm 20 cm x 20 cm x 20 cm (ENEA)
Material	Water
Radiation qualities	According to Table 3
Air temperature:	20 °C
Air pressure	1013,25 hPa
Rel. humidity	50 %
Absorbed dose rate to water	> 0,2 mGy/s
Size of the radiation field at the point of measurement (50% Isodose)	10 cm x 10 cm or circular with diameter 10 cm
Measurement depth	2 g/cm^2
Distance between source and point of measurement	100 cm 50 cm (LNE-LNHB) 61,5 cm (VSL b.V.)
Polarizing voltage	300 V (measure at both polarities)

4.3 Reference conditions for the calibration in terms of air kerma

Radiation qualities:	According to Table 3
Air temperature:	20 °C
Air pressure:	1013,25 hPa
Rel. humidity:	50 %
Air kerma rate:	> 0,2 mGy/s
Size of the radiation field at the point of measurement (50% Isodose):	About 10 cm x 10 cm or circular with diameter of about 10 cm Circular, diameter 7 cm (at LNE-LNHB)
Distance between source and point of measurement:	100 cm 120 cm (LNE-LNHB)
Polarizing voltage	300 V (measure at both polarities)

4.4 Additional measurements in the depth of 5 g/cm^2

The reference depth in the water phantom was agreed to be 2 g/cm^2 (clause 4.2). It was agreed that all participants shall perform additional charge measurements under otherwise equal conditions with the transfer chambers positioned in the depth of 5 g/cm^2 at all comparison radiation qualities (clause 3). Note that the distance between the source and point of measurement shall remain constant (i.e. move the phantom, not the chamber). If possible, these measurements shall also be done at both polarities. The charge ratio obtained for the two depths will be used to evaluate a suitable beam qualifier.

5 Course of comparison

There will be a star-shaped circulation of the chambers between PTB and the participants. PTB pays for the transport of the chambers to the participants. The participants pay for the transport of the chambers back to PTB. After every participants calibration PTB will perform chamber constancy checks. The chambers should stay at the participant's site for no longer than 2 weeks. The report of results (clause 5.2) should be sent to the coordinator within 2 weeks after the calibration.

5.1 Prospective time schedule

The comparison is scheduled to commence in June 2014 (starting with PTB's measurements) and expected to be completed in November 2014. The proposed schedule is shown in Table 2.

Table 2: Proposed schedule of the comparison (June 2014 until November 2014)

Participant	Date of Chambers leaving PTB for participant	Measurement duration at laboratory	Date of chamber leaving participant for PTB
PTB, Germany		16-27 June 2014	
CEA, LIST, France	07 July 2014	14-25 July 2014	28 July 2014
ENEA, Italy	25 Aug. 2014	01-12 Sep. 2014	15 Sept. 2014
MKEH, Hungary	29 Sept. 2014	06-17 Oct. 2014	20 Oct. 2014
VSL B.V., The Netherlands	03 Nov 2014	10-21 Nov. 2014	24 Nov. 2014

Notes:
1. Duration of measurement for one laboratory is two weeks.
2. Transportation time for the chambers from the PTB to a participant is about one week, vice versa.
3. Duration of constancy measurements at PTB laboratory is about one week.

5.2 Report of results

The **report of the results** shall at least contain the following information:

- Description of the radiation field (type of x-ray source, field size (50% Isodose), approximate air kerma rate at 1 m distance and 10 mA tube current, photon fluence spectra if measured, HVL and mean energies of the radiation qualities used for the comparison)
- Description of the set-up (electrometer type, connector types used, traceability of the electrometer calibration)
- Climatic conditions prevailing in the calibration laboratory during the calibration (Temperature, Pressure, Humidity)
- Complete uncertainty budget of the air kerma rate measured with the primary standard
- Complete uncertainty budget of the absorbed dose to water rate measured with the primary standard
- Leakage and signal currents of the transfer chambers during the measurements
- Calibration coefficients of the three transfer chambers for both polarities in terms of air kerma free in air and absorbed dose to water
- Results of the additional charge measurements in the depth of 5 g/cm^2

- Complete uncertainty budget of the calibration coefficients

The uncertainties shall be given in accordance with the ISO Guide to the expression of uncertainties in measurements (GUM) [4].

5.3 Procedure for handling the results of the pilot laboratory

The pilot laboratory will participate in the comparison. It shall finish its measurements and report of results prior to all other participants. The report on these measurements will be sent to the EURAMET TC-IR Chair Lena Johansson before the first participant following the pilot's measurements has finished its measurements (i.e. before July 25 according to Table 2). This procedure should be a measure of confidence. For the purpose of constancy checks, the pilot laboratory will repeat its determination of the calibration coefficients at selected radiation qualities after every participant's measurements.

5.4 Evaluation of the results

The pilot laboratory will evaluate the comparison on the basis of the reports of results (see 5.2) given by the participants. In general, the mean value obtained from measurements at both polarities will be regarded as the result for each transfer chamber at one radiation quality. The final result will be evaluated as the mean value of the single results obtained for each of the three transfer chambers.

5.4.1 Calibration coefficients in terms of air kerma

This comparison is not aimed at a comparison of air kerma standards but the calibration coefficients in terms of air kerma, N_K, give valuable additional information about the consistency of the absorbed dose calibration coefficients, $N_{D\mathrm{w}}$, for the different radiation qualities used at the participant's sites (see next clause). If one wants to use the N_K results in such a way, it is necessary to know the differences of N_K between the participants. Therefore it is suggested, to evaluate the ratios and uncertainties of those of the N_K values obtained by the participants for identical radiation qualities. These results will mainly be used for the evaluation procedure according to equation (1) described in following clause. In addition, the consistencies of the results for the CCRI-qualities obtained by the participants in the current exercise with those obtained in the bilateral key comparisons with the BIPM (BIPM.RI(I)-K3) will be checked. But it is not intended to publish these results as an additional indirect K3-key comparison result.

5.4.2 Calibration coefficients in terms of absorbed dose to water

The consistency of the calibration coefficients in terms of absorbed dose to water and air kerma free in air obtained by the participants will be evaluated by the equation:

$$N_{D_\mathrm{w}} = N_K * \left(\frac{\overline{\mu}_\mathrm{en}}{\rho} \right)^\mathrm{d}_\mathrm{w,a} * k_\mathrm{ch} * k_\mathrm{sheath} , \quad (1)$$

where $(\bar{\mu}_{en}/\rho)^{d}_{w,a}$ is the mean value of the water-to-air ratio of the mass-energy-absorption coefficients at the depth *d* in water and k_{ch} is the overall chamber correction factor that accounts for the change in the chamber response due to the displacement of water by the ionization chamber (air cavity plus wall) and the presence of the chamber stem, the change in the energy, and the angular distribution of the photon beam in the phantom compared to that used for the calibration in air, and k_{sheath} is a correction factor for the effects of a waterproofing sheath. The transfer chamber of type TM30013 is waterproof, thus k_{sheath} must not be applied. The correction factor k_{ch} was shown [2] to vary by less than 0,5 % for qualities generated with tube voltages between 70 and 280 kV (TH 70 to TH 280 in Ref. [2]). $(\bar{\mu}_{en}/\rho)^{d}_{w,a}$ is obtained with relative uncertainties of about 0,3%. Mean values for the radiation qualities of Table 3 were calculated based on the mono-energetic ratios shown in Figure 1 and averaged with photon fluence spectra measured at PTB. Photon fluence spectra in 2 cm and 5 cm depth of a water phantom were obtained by the EGSnrc [5] user code FLURZnrc [6] using a parallel beam of photons of circular diameter 10 cm and the measured free-in-air spectra incident on a cylindrical water phantom of diameter 30 cm. Results for the qualities TH 70 – TH 280 are shown in Table 4 together with the chamber correction factor k_{ch} as published in [2]. Similar values can be expected for the transfer ionisation chambers of the same type.

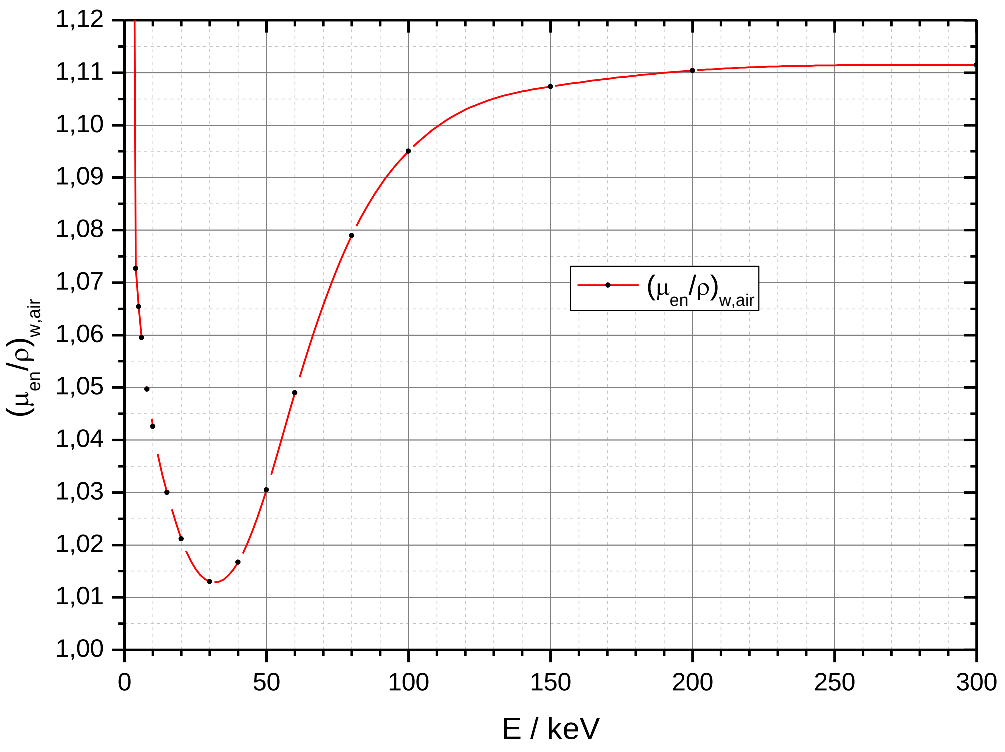

Figure 1: Ratio of water-to-air mass energy-absorption coefficients as a function of photon energy. Mass energy-absorption coefficients of air and water were taken from [7].

From Table 4 it is obvious that values of $(\bar{\mu}_{en}/\rho)^{d=2\,cm}_{w,a}$ and $(\bar{\mu}_{en}/\rho)^{d=5\,cm}_{w,a}$ differ by no more than about 0.2 % so that calibrations in different depths will not result in significantly different calibration coefficients. The quality correction factor k_Q with respect to the air kerma calibration coefficient normalized at TH280 of the chamber TM30013 was shown to be almost equal to one for TH70 to TH280 [2]. Thus it can be expected that this chamber type will indicate correctly the air kerma in the different depths of a water phantom because the air kerma response is almost independent of the photon fluence spectrum in this energy range. In summary, according to the results described above it is expected that the ratios $N_{D\mathrm{w}}$ / N_K of the transfer chambers are close to $(\bar{\mu}_{\mathrm{en}}/\rho)^{\mathrm{d}}_{\mathrm{w,a}}$ within less than 1 %. Therefore, this chamber type is well suited for this type of comparison and the conclusions which can be made.

Table 4: Ratio for water-to-air of the mean mass energy-absorption coefficients averaged over the incident photon spectrum and at 2 cm and 5 cm depth in a reference water phantom, the chamber correction factor k_{ch} and the radiation quality correction factor with respect to the air kerma calibration coefficient at TH280 of the chamber TM30013-425 as published in [2]. The values for the CCRI qualities were obtained from additional calculations and measurements according to the methods described in [2].

Radiation quality	Tube voltage kV	Mean energy keV	$(\bar{\mu}_{\mathrm{en}}/\rho)^{\mathrm{air}}_{\mathrm{w,a}}$	$(\bar{\mu}_{\mathrm{en}}/\rho)^{\mathrm{d=2\,cm}}_{\mathrm{w,a}}$	$(\bar{\mu}_{\mathrm{en}}/\rho)^{\mathrm{d=5\,cm}}_{\mathrm{w,a}}$	k_{ch}	k_{Q}
TH 70	70	42.0	1.020	1.020	1.021	1.004	1.000
CCRI 100	100	50.9	1.030	1.029	1.031	1.005	0.999
TH 100	100	52.8	1.033	1.031	1.032	1.005	0.999
TH 120	120	60.0	1.043	1.038	1.040	1.007	0.997
CCRI 135	135	67.2	1.055	1.047	1.047	1.007	0.998
TH 140	140	67.6	1.055	1.047	1.048	1.007	0.998
TH 150	150	78.5	1.071	1.060	1.059	1.006	0.999
CCRI 180	180	84.8	1.076	1.065	1.064	1.006	0.999
TH 200	200	99.4	1.089	1.078	1.076	1.005	0.998
TH 250	250	122.2	1.099	1.090	1.089	1.003	0.999
CCRI 250	250	122.6	1.098	1.089	1.087	1.003	0.999
TH 280	280	146.3	1.105	1.098	1.097	1.002	1.000

The final result will be the comparison of the primary absorbed dose to water standards of the participants reflected by the mean values and uncertainties of the final calibration coefficients of the three transfer chambers obtained at the same or at least at sufficiently similar radiation qualities. In addition, information is gained about the consistency of the ratio $N_{D\mathrm{w}}$ / N_K for the chamber type TM30013 as obtained by the participants.

5.5 Publication of the results

After finishing the whole program with all the participants the pilot laboratory will prepare a Draft A of the report of the results of this comparison. The Draft A will be circulated for comments and discussion of the results and once agreement is reached, the revised report Draft B, will be produced as the official final report of the comparison. This will be the first comparison between recently developed primary standards of absorbed dose to water in the medium-enery x-ray range. In addition, results of N_{Dw} / N_K for this chamber type will be obtained. Therefore it is justified and suggested to publish the results in *Phys. Med. Biol.* and/or *Metrologia*. The results may also be useful for the support of CMC entrances of the participant's institutes. For this purpose it is suggested to publish the results on the BIPM Key Comparison Data Bank (KCDB).

6 References

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APPENDIX B: Complete addresses of the participants (used for shipment!)

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