Comparison protocol for the calibration of KAP meters in terms of air kerma area product

1. Introduction

The air kerma–area product, P_{KA}, is the integral of the air kerma over the area of the X ray beam in a plane perpendicular to the beam axis, thus

$$P_{KA} = \int K(x,y)\,dx\,dy$$

The recommended unit is Gy·cm^2 [1], although some other units are often used (Gy mm^2 or μGy m^2) in practice.
The P_{KA} is usually measured by Air Kerma Area product meters (KAP meters).
The KAP meters are widely used in clinical diagnostic radiology dosimetry, especially in fluoroscopy, interventional radiology, general radiography and dental radiography.
Special procedures are applied for their calibration.
The IAEA Coordinated Research Programme (CRP E2.10.08), Activity 3, focuses on the KAP meter calibration comparison which will be carried out by the participating calibration laboratories in four countries (CZ, FI, GR, RS).
Simultaneously, a similar comparison will be performed between the partner laboratories of EURADOS WG 12, SG 3: Technical aspects on DAP calibration and CT calibration to include three other countries (ES, IT, FI, GR, PL).
Finally, during the last annual EURAMET IR-CP meeting (Bratislava, 2010) some secondary standard dosimetry laboratories (SSDL) expressed their interest to participate in such a comparison in at least five other countries (DK, FI, GR, IS, NO, RO, SE, etc).
Therefore, a EURAMET project is being conducted for the calibration comparison of KAP meters. Two KAP meters will be circulated between participating laboratories and the calibration coefficients in terms of P_{KA} and the associate uncertainties will be compared.
Since the KAP meter calibration depends on the air kerma (rate) and the area of the radiation field, a diagnostic radiology (DR) chamber suitable to measure the air kerma (rate) will be circulated as well and it should be calibrated in terms of air kerma. Thus the differences in the air kerma calibration coefficients and those of the air kerma area product can be compared separately.
The project will enable participating calibration laboratories to test and verify their calibration methods and capabilities and to support the relevant Calibration and Measurement Capabilities (CMCs) referenced to the International System of Units (SI) at the BIPM by comparing their results with comparison reference values.

2. Comparison methodology

2.1 Participants

The participants are presented in table below

LIST OF PARTICIPATING LABORATORIES

	EURAMET member
	EURAMET member and participant in both IAEA & EURADOS projects
	EURAMET member and participant to EURADOS project.
	Not EURAMET member, IAEA CRP project participant
	Not EURAMET member, EURADOS project participant

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2.2 Pilot laboratory

The ICRL/GAEC-EIM, Greece will be the pilot laboratory, which will be responsible for the overall coordination of the comparison. It will follow the rules of the CIPM MRA in compiling and analysing the results of the calibrations, particularly for potential outliers, and will prepare a summary Draft A report with conclusions (including degrees of equivalence) for comments and checking by each participating laboratory. The pilot laboratory will also prepare the final reports to EURAMET and the BIPM (KCDB).

2.3 Comparison procedure

- The first calibration will be carried out by the pilot laboratory (GAEC), including constancy checks of the KAP meters and the DR chambers, before mailing to the second laboratory in accordance with the agreed order and time schedule.
- After the calibration at the second laboratory, the instruments will be shipped to the third laboratory.
- After every three laboratories, the instruments will be returned to the pilot laboratory for an interim re-calibration, hereafter the circulation is continued to the remaining laboratories with the same principles in accordance with an agreed order and schedule of calibrations.
- Within 2 weeks after the calibration, each laboratory will send to the pilot laboratory: the calibration report with the calibration coefficients and the associate uncertainties as well as a short description of the calibration procedure (including a few photographs and drawings if appropriate); the pilot laboratory having first submitted its own first set of results to the CCRI Executive Secretary.

2.4 Calibration coefficients

The two KAP meters (IBA KERMA-X and RADCAL PDC – see section 3) will be calibrated in terms of P_{KA} (in Gy cm^2 / digit) for incident and/or transmitted radiation as indicated below, so the $N_{PKA,\mathrm{inc}}$and/or $N_{PKA,\mathrm{trans}}$ can be deduced for each x-ray beam quality.

The diagnostic radiology chambers (MAGNA A650 and RADCAL PDC – see section 3) will be calibrated in terms of air kerma (K_i) (in mGy / nC for the MAGNA A650 and in mGy / digit for the PDC), so the N_K can be deduced for each x-ray beam quality.

All appropriate correction factors (e.g. for air density, ion recombination, etc) should be taken into account and reported in detail within the calibration report.
The calibration coefficients and the associated uncertainties will be strictly confidential during the comparison process. To this extent, these values, as well as other relative information will not be announced or distributed between partners. When the comparison is completed, the pilot laboratory will distribute a draft report.

2.5 Radiation qualities for KAP meters and DR chambers calibration

The KAP meters and the DR chambers should be calibrated at the following radiation qualities:

- Reference beam qualities according to IEC 61267 [2]
  RQR 3 (50 kV) - RQR 5 (70 kV) - RQR 6 (80 kV) - RQR 8 (100 kV) - RQR 9 (120 kV)

For transmitted radiation measurements, the KAP meter contributes to the beam quality, so the above reference radiation qualities are altered. The laboratory should use the above mentioned reference beam qualities for the x-ray system emerging radiation beams that are incident on the KAP meter. The use of appropriate corrections, the traceability of measurement and the additional contribution to the uncertainties for the transmitted radiation cases should be provided by the participating laboratory.

- Non-reference beam qualities :
  Non-reference beam qualities are selected to simulate the clinical x-ray beams that are often applied in practice.
  On a voluntary basis the laboratories may perform the KAP meter and DR chamber calibrations at the non-reference beam qualities presented in table 1. At such copper filtrations, the thickness of aluminum filtration is not so important. So, the laboratories may use aluminum thickness close to the values (table 1) - the Cu thickness should be precise.

Table 1 : Non standard radiation qualities

# series	**Tube voltage / kV**	**Total tube filtration**
A	50, 80, 100, 120	3.0 mm Al + 0.1 mm Cu
B	50, 80, 100, 120	4.0 mm Al + 0.2 mm Cu
C	80, 100, 120	1.5 mm Al + 0.9 mm Cu

The HVL values should be defined by the laboratories and the thickness of Al and Cu together with the HVL at every tube voltage should be reported. Details on the traceability of the standards, measurements and calibration at these qualities should be provided by the participating laboratory.

2.6 Radiation field sizes (area) for KAP meter calibration

According to [3], a circular or square lead aperture should be available with a known diameter or width between about 40 and 60 mm. The laboratory should be able to position this aperture in front of the plane of measurement. A suitable distance between the aperture and plane of measurement is 50 mm.
The radiation field size (area) at the reference plane of measurement and its uncertainty should be reported in the calibration report.
In order for the calibration results to refer to the same irradiation area, the pilot laboratory (in cooperation with other volunteer laboratories) will investigate the irradiation area dependence of response of the KAP meters and appropriate correction factors will apply.

2.7 Comparison environmental conditions

The calibration coefficients should refer to the standard reference environmental conditions:
Temperature : 293.15 ^{o}K (20 ^{o}C) , Pressure : 101.325 kPa and R.H. : 50%

The actual environmental conditions during the calibrations, including the relative humidity, should be recorded and reported in the calibration report. Since the instruments may need several hours to stabilize, especially after transport, they should be placed into the measuring room the day before measurements.

2.8 Uncertainties

The uncertainties should be evaluated according to the IEC GUM 1995 [4] and reported in detail in the calibration report of the laboratory. The overall expanded uncertainty should be evaluated with coverage factor $k = 2$.

3. Instruments and calibration conditions

The instruments for the comparison are :

3.1 IBA Kerma-X plus (IBA SCANDITRONIX WELLHOFER)

Measuring device : KermaX-plus DDP TinO, Model 120-205, s/n 01E01232
KAP Ionization chamber : IBA Model 120-131 TinO, s/n 01A00120
Accessories: (i) SCANDITRONIX Power Supply Type 8713 MED, (ii) Cable AWM 20251 with adaptor end and (iii) Adaptor cable RS 232 port.
The instrument will be provided by the IRCL/GAEC-EIM, Greece

The reference point of the KAP ionization chamber is the geometrical centre (middle line) of the effective volume, i.e. the reference plane is located at half the KAP thickness below the front surface of the KAP ionization chamber. The front surface is the surface facing the X-ray tube and it has been marked.

The KAP ionization chamber is vented, so appropriate corrections for air density should be applied.
According to the manufacturer specifications, the nominal active area of the KAP ionization chamber is rectangular with dimensions 146 mm x 146 mm (nominal values). The chamber has an optical transparency >75%.
This KAP ionization chamber can be used for both incident and transmitted radiation.
It measures simultaneously: the Entrance dose (mGy), Entrance dose rate (mGy/s), P_{KA}(μGy m^2), P_{KA}rate (μGy m^2/s) and Exposure time (with time resolution: 500 μs).

In this comparison, the device must read the P_{KA} quantity, i.e. the accumulated P_{KA} (μGy m^2) over a constant time period (60 s accumulation time is suggested). The P_{KA} rate values (μGy m^2 / s) should not be used for the calculation of the calibration coefficients (please refer to the operation instruction for the selection of this mode).

The resolution of the P_{KA} measurement is 0.01 μGy m^2. The device accumulates the P_{KA} values. Zeroing between successive exposures might be used using the RESET button.

The Kerma-X KAP meter will be calibrated at the standard and (on a voluntary basis) at the non-standard radiation beam qualities referred to section 2.5 for both incident and transmitted radiation.

3.2 Radcal Patient Dose Calibrator PDC (Radcal Corp)
s/n 07 0008, part no 165 00 01
Accessories : **(i)** charger **(ii)** socket adapter UK-EE **(iii)** Manual

The instrument will be provided by the IAEA.
The main device consists of the measuring device (including the display unit) and the KAP ionization chamber.
The PDC is a reference class instrument for "field calibration" of patient dose measurement and control systems. The PDC measures the P_{KA} and the air kerma (rate) during an exposure. Therefore, in this project, the PDC will be used both as a KAP meter and a DR chamber and it will be calibrated in terms of P_{KA} and K_i.

For the consistency of the comparison, the measurements should be performed in the accumulated air kerma (mGy) and the accumulated P_{KA} (μGy m^2) over a constant time period mode (60 s accumulation time is suggested). The air kerma rate (mGy/min) or the P_{KA} rate (μGy m^2 / min) values ***should not*** be used for the calculation of the calibration coefficients.

The reference point of the KAP ionization chamber is the geometrical centre of the front surface of the device, i.e. the reference plane coincident with the front surface of the device.

The PDC's ionization chamber(s) is vented. However, the device may apply automatic corrections for air density through its pressure and temperature sensors. The user should check if those correction factors are valid and applied appropriately (please refer to the operation instruction).
According to the manufacturer specifications the nominal active area of the KAP ionization chamber is rectangular with dimensions 300 mm x 300 mm (nominal values). The chamber is not optically transparent.
This KAP ionization chamber is used only for incident radiation.
It measures simultaneously: Entrance dose (mGy), Entrance dose rate (mGy/s), DAP (μGy m^2), DAP rate (μGy m^2/s) and Field size (mm^2)
When the PDC is used for air kerma measurements, the irradiation field size should exceed 10 cm in diameter, as indicated on the device front surface and manual.
The resolution of the P_{KA} measurement is 0.01 μGy m^2. There are LOW and HIGH measuring ranges. In this comparison the LOW RANGE will be used.
The device accumulates the P_{KA} values. Zeroing between successive exposures is performed automatically or by using the RESET button.

The PDC KAP meter will be calibrated in terms of P_{KA} at the standard and (on a voluntary basis) at the non-standard radiation beam qualities referred to section 2.5 only for incident radiation.
Also, the PDC will be calibrated in terms of air kerma (K_i) at the standard and (on voluntary basis) at the non-standard radiation beam qualities.

3.3 MAGNA A650 ionization chamber
Ionization chamber EXRADIN - Standard Imaging
MAGNA A650, 3 cc, REF 92650 s/n D082612
***Accessories* : (i)** Protection cap **(ii)** Manual

The instrument will be provided by the IRCL/GAEC-EIM, Greece

This parallel plate ionization chamber is a reference class instrument - with 3 cm^3 active volume having a Kapton conductive film entrance window. It has a TNC connector and it can be connected to an electrometer.
In this project, the chamber will be circulated alone (without an electrometer). The laboratories should use their own electrometer.

The polarizing voltage is 300 V, with the negative polarity to the middle shielding electrode (guard ring); the outer shielding (wall) is on earth potential. With this polarity configuration the displayed charge values on the electrometer should be of positive sign (+).

In this comparison, the reference point is the geometrical center of the chamber front surface (entrance window). Please ignore the reference point specifications presented in the chamber manual.

The MAGNA chamber will be calibrated in terms of air kerma (K_i) at the standard and (on voluntary basis) at the non-standard radiation beam qualities.

4. Schedule and responsibilities for the costs

Each laboratory will have one week to complete the calibrations and another week to take care of the receipt, unpacking, re-packing and sending of the instruments to the next laboratory.
Each laboratory should calibrate both KAP meters in terms of P_{KA} at the standard beam qualities of table 1 (for incident and transmitted radiation for the KERMA-X and for incident radiation for the PDC) and on a voluntary basis at the non-reference beam qualities of table 1 (again for incident and transmitted radiation for the KERMA-X and for incident radiation for the PDC).
Also, the MAGNA chamber and the PDC in terms of air kerma at the standard beam qualities of table 1 and on a voluntary basis at the non-reference beam qualities of table 1.

This intensive work schedule requires the establishment of standard and non-standard beam qualities and KAP meter calibration procedures by the laboratories in advance, as well as the completion of all necessary internal program arrangements to perform the measurements on time.
The schedule of the calibrations for the participating laboratories is presented below.

Laboratory	Period for calibration	Period for transport	Comments
Pilot laboratory, GAEC, Greece *	28/3-1/4/2011	4-10/4/2011	Initial calibration - 1st
NIOM, Poland	11-15/4/2011	18-24/4/2011	Easter coincident with transport period
UPC, Spain	25-29/4/2011	2-8/5/2011	
STUK, Finland	9-13/5/2011	16-22/5/2011	
GAEC, Greece	23-27/5/2011	30/5-5/6/2011	Re-calibration - 2nd
LNHB, France	6-10/6/2011	13-19/6/2011	
SURO, Czech	20-24/6/2011	27/6-3/7/2011	
	4-8/7/2011	11-17/7/2011	Vacancy
GAEC, Greece	18-22/7/2011	25-31/7/2011	Re-calibration - 3rd
SIS, Denmark	1-5/8/2011	8-14/8/2011	
NRPA, Norway	15-19/8/2011	22-28/8/2011	
			Short summer brake
PTB, Germany	12-16/9/2011	19-25/9/2011	
GAEC, Greece	26-30/9/2011	3-9/10/2011	Re-calibration – 4th
SSM, Sweden	10-14/10/2011	17-23/10/2011	
VINCA, Serbia	24-28/10/2011	31/10-6/11/2011	
IFIN, Romania	7-11/11/2011	14-20/11/2011	
GAEC, Greece	21-25/11/2011	28/11-4/12/2011	Re-calibration – 5th
MKEH, Hungary	5-9/12/2011	12-18/12/2011	
GR, Iceland	9-13/1/2012	16/-22/1/2012	
IAEA	23-27/1/2012	30/1-5/2/2012	
GAEC, Greece	6-10/2/2012	13-19/2/2012	Re-calibration – 6th
ITN, Portugal	20-24/2/2012	27/2-4/3/2012	
SCK-CEN, Belgium	5-9/3/2012	12-18/3/2012	
VSL, Netherlands	19-23/3/2012	26/3-1/4/2012	
GAEC, Greece	2-6/4/2012	9-15/4/2012	Re-calibration – 7th
IRP DOS, Italy	16-20/4/2012	23-29/4/2012	
CMI, Czech	30/4-4/5/2012	7-13/5/2012	
	14-18/5/2012	21-27/5/2012	
GAEC, Greece	28/5-1/6/2012		Final calibration

Each laboratory will cover all costs of their own calibrations, including the above reporting, and the further sending of the instruments to the next laboratory.

5. Transport of instruments

Each laboratory will take all necessary provision for the safe transport of the instruments to next participating laboratory. The transport costs and insurance costs will be undertaken by each laboratory. An insurance of 15,000 Euros against damage or loss of the packages is proposed. The transport arrangements and shipping details will be announced by e-mail to the next participating laboratory and for information of the pilot laboratory. Upon receipt of the instrument package, the previous participating laboratory (the sender of the package) and the pilot laboratory should be informed. Package damage or signs of damage should be reported immediately to both laboratories, the previous laboraotry and the pilot laboratory.

6. Evaluation of the comparison results

Calibration in terms of P_{KA}

The calibration coefficients provided by each participating laboratory will be corrected for the irradiation area dependence of response. The appropriate correction factors for this influence quantity will be measured by the pilot laboratory (in cooperation with other volunteer laboratories) for both the KAP meters. Therefore, the deduced $N_{PKA,\text{Lab-cor}}$ calibration coefficients will refer to the same, normalized, irradiation area.

The result of each KAP meter comparison, R_{PKA} will be expressed as

$$R_{PKA} = \frac{N_{PKA,\text{Lab-corr}}}{N_{PKA}}$$

where the $N_{PKA,\text{Lab-cor}}$ is the calibration coefficient of each laboratory at a given radiation quality corrected for the irradiation area dependence of response and N_{PKA} the reference calibration coefficient at the same radiation quality, which will be derived from the calibrations at the primary standard dosimetry laboratories PSDLs (N_{PKA} equals the mean calibration coefficients from all participating PSDLs).

The uncertainty of the R_{PKA} will be evaluated from

$$u_{R_{PKA}} = \sqrt{u^2_{N_{PKA,lab}} + u^2_{N_{PKA}} + u^2_{stab}}$$

The uncertainty u_{stab} (with $k = 1$) refers to the stability of each instrument and will be derived by the pilot laboratory from the standard deviation, s_i of all its own periodic measurement results, at each radiation quality i.

The R_{PKA} values provide relative information of the calibration standards and procedures followed by each laboratory at a given radiation quality.

Calibration in terms of K_i

Using a similar evaluation, R_K values and uncertainties will be deduced for the calibration of each ionization chamber in terms of K_i.

Comparison between the R_{PKA} and the R_K values (at the same beam quality) will provide relative information on the calibration set-up and procedures (including radiation field area, reference point of the KAP chamber, homogeneity of radiation beam) followed by each laboratory for the KAP meter calibrations.

REFERENCES

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3.International Atomic Energy Agency (IAEA). Dosimetry in diagnostic radiology: An international code of practice, Technical reports series No 457. STI/DOC/010/457, ISBN 92-0-115406-2; 2007.

4.International Organization for Standardization (ISO). Guide to the Expression of Uncertainty of Measurement. ISO, Geneva; 1995.