Progress report on the photon dosimetry at CMI

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Maintenance and development of standards

Development of a free air chamber for low-energy X-rays:

Czech Metrology Institute provides the traceability for measurement instruments in radiodiagnostic qualities of X-rays by means of Czech national standard of exposure and air kerma No. ECM 440-5/11-049. This national standard has been built as a secondary standard, i.e. it is based on a set of secondary cavity ionizing chambers covering all basic photon energy regions, which are traceable to primary standards abroad.

In 2011 CMI's management made a decision to build a primary standard in form of a free-air chamber (FAC) for low-energy X-rays. During 2011 a physical design of the FAC, solutions of important design nodes and drawings were created, the chamber was then manufactured including precise dimension measurement using a CMM, it was equipped with connectors, wires and voltage divider, and models of the FAC were created (MC model in the MCNPX code and finite-elements model in the QuickField application). In 2012 computations and experiments were performed in order to verify the expected parameters and stability of measurements, to determine the correction factor values, and finally the chamber performance was verified by comparison to a primary standard.

The FAC is built in the usual way as a plan-parallel ionization chamber. A beam of X-rays enters the shielded metal box through an opening of an area A, then it travels between two plan-parallel electrodes and leaves the box through an opening on the opposite side without touching the structure of FAC. An electric field exists between these electrodes; its homogeneity is maintained by a set of guarding rings connected to equidistantly divided polarizing potential. Electric charge released by photons interactions is then collected by collecting electrode of length l and measured as ionization current.

The value of air kerma $K_{A,air}$ at the entrance opening can be determined from measured value of ionization current as

$$K_{A,air} = \frac{Q}{A.l.\rho}\frac{W_{air}}{e}\frac{\prod k_i}{(1-g)}$$

or

$$\dot{K}_{A,air} = N_{K,air}.I.\prod k_i$$

where

$$N_{K,air} = \frac{K_{A,air}}{Q} = \frac{W_{air}}{e}\frac{1}{A.l.\rho.(1-g)}$$

Basic dimensions of the chamber ensure that the chamber can be used for photons of energy up to appr. 50 keV, and they are almost identical to those of the low-energy BIPM chamber.

Values of basic dimensions are as follows:

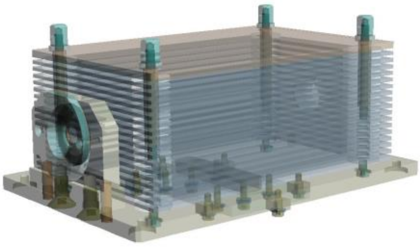
Inner cavity: 70 x 70mm
Aperture diameter: 8.257; 10.164 or 12.457mm
Aperture area: 53.547; 81.137 or 121.876mm^2

Measuring volume: 0.7763; 1.1763 or 1.7670cm^3
Collecting electrode length: 13.994mm
Air gap (total width of both sides): 1.008mm
Aperture to collecting electrode distance: 100.007mm

Calibration coefficient values for individual aperture diameters were calculated from above mentioned dimensions: $N_{K,air}$ = 3.6313.10^7, 2.3965.10^7 or 1.5955.10^7 Gy/C (for 101.325 kPa and 20°C).

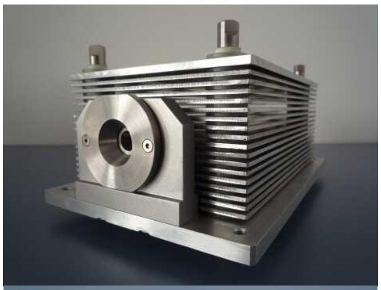
Here are several pictures of the FAC.

Image of inner chamber in a CAD application.



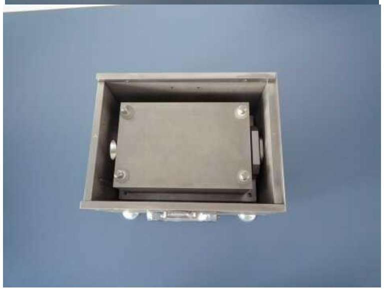
Position of inner chamber in outer case.

Inner chamber with the aperture holder (in front) and a set of guarding rings. Glass pads separating individual guarding rings are visible as well.



Inner chamber with the high voltage electrode removed, where the collecting electrode with the air gap is visible (in the middle).

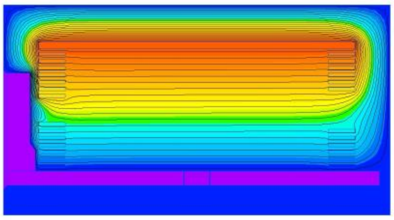
Inner chamber is placed into the outer case ensuring the mechanical protection and radiation and electromagnetic shielding of the chamber.



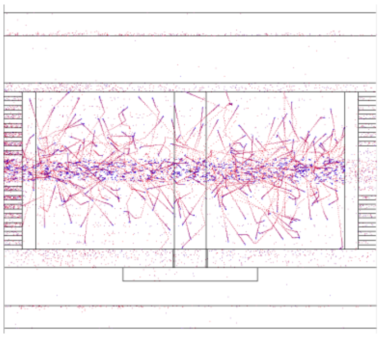
View of the chamber with closed outer case (view from the entrance opening).

Back wall of the chamber with voltage divider and connectors for high voltage and ionizing current.

Simulation of the electric field inside the chamber using the QuickField application.



Simulation of electron tracks in the chamber for N60 quality (representing the appr. upper energy limit of the chamber) using the MCNPX code.



In order to verify the FAC performance and validity of correction factors, a comparison to the Austrian primary standard for low-energy X-rays was arranged thanks to the generosity of Franz-Josef Maringer and Andreas Steurer from BEV. This comparison was not a registered bilateral comparison, it was meant as a final check of measuring chain and preliminary verification of metrology characteristics of the CMI's FAC.

Comparison was performed for the N10, N15, N20, N25, N30, and N40 qualities and repeated twice in two days. The FAC was placed into an axis of X-ray beam and its response was compared to the reference value of the BEV primary standard by means of a monitoring chamber used as a comparator. For both measurements the position of the chamber was adjusted again and two different high voltage sources were used.

A ratio of the reference value of BEV to the air kerma rate determined by the CMI's FAC with all correction factors applied is shown in the table below, separately for both days and as an average of both measurements.

Quality	BEV/CMI 8.10.2012	BEV/CMI 9.10.2012	BEV/CMI avg.
N10	0.9957	0.9934	0.9945
N15	0.9967	0.9942	0.9954
N20	0.9998	0.9970	0.9984
N25	1.0012	0.9973	0.9992
N30	1.0028	0.9989	1.0008
N40	1.0036	0.9996	1.0016

The results are in very good agreement, however a trend can be observed indicating some effect which was not correctly taken into account in the correction factors, possibly in the correction for attenuation in air.

The primary chamber is nevertheless considered ready for key comparison and for standardization of low-energy X-ray beams.

Traceability of the Czech national standards of air kerma and absorbed dose to water:

In 2011, reference chambers PTW TW23344 (absorbed dose to water, low-energy X-rays) and TW30013 (absorbed dose to water, medium-energy X-rays) were calibrated at the PTB primary laboratory. In 2012, reference chambers Radcal RC6M (air kerma, Mo/Mo mammography qualities of X-rays), Exradin A4 (air kerma, medium-energy X-rays, Cs-137 and Co-60) and NE 2571 (absorbed dose to water, Co-60) were calibrated at the BIPM primary laboratory, reference chamber Radcal RC60 (air kerma, RQR qualities of X-rays) was calibrated at the PTB primary laboratory.

New source installed:

New X-ray machine was installed and put into operation in 2012. It is an Isovolt Titan E with a Panalytical 100 kV tube with Mo-anode and added filtration of 30µm of Mo.

International activities

In 2011 CMI participated in the supplementary comparison EURAMET.RI(I)-S9 Calibration of kerma-area-product (KAP) meters used in radiology.

CMI has been regularly participating in the TLD audit organized by IAEA for the SSDLs.

Services performed

Routine verification and calibration of measuring instruments according to the Czech Metrology Act (the main task of CMI).

- Calibration of irradiation facilities (8 visits) in other Czech metrology centers
- Verification of measuring instruments acc. to the Czech Metrology Act (226 instruments for radiation protection, 13 standard class instruments for radiotherapy, 20 instruments for X-ray diagnostics, 14 systems of personal integral dosimetry)
- Type approval of measuring instruments (5 new approvals) acc. to the Czech Metrology Act

Personnel

Current status of the staff in the photon dosimetry laboratory of CMI is as follows:

2 scientists, 2 technicians (all FTJ)