Dosimetry for Radiotherapy and Diagnostic Radiology at PTB Progress Report

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Realization and dissemination of the unit of the absorbed dose to water

Owing to dramatic delays in the delivery of a new 300 TBq ^{60}Co-source the progress in implementing the water calorimeter as PTB's primary standard has essentially come to a standstill. Currently calorimetric measurements can only be performed in the radiation field of the old source which under reference conditions does not deliver a suitable dose rate any more. Nevertheless, most parts of the quality assurance system for the calorimeter, including the uncertainty budget for the determination of absorbed dose to water in ^{60}Co-radiation, are in the final stages of development. Work is in progress to develop a transportable water calorimeter for use in high-energy photon and electron fields.

ESR-spectrometry on the basis of alanine will be used as a secondary standard for absorbed dose to water for such irradiation conditions for which the water calorimeter can only be operated with higher uncertainties, e.g. in small sized fields.

As a first step a reference probe for the spectrometer has been developed to normalize the measured alanine signal to the well-known reference signal. This way, the influence of short-term changes of environmental conditions on the signal of a 1 kGy-irradiated alanine probe could be reduced by a factor of about ten. As the influence of such changes over periods of several days or weeks can not be reduced with the same effectiveness, a day-by-day calibration of the ESR-spectrometer will be used. Work is in progress for a better long-term stabilization of the spectrometer regarding temperature and humidity.

For alanine probes irradiated with doses lower than about 50 Gy it is expected to achieve dose determinations with a repeatability of less than 0.5 % in this year. For this purpose the evaluation algorithms and the background signal deduction are being refined.

High-energy photon and electron radiation

Work to establish reference fields for high-energy photon and electron beams is in progress. One purpose, essential for conducting quality audits, is to irradiate passive dosemeters in a water phantom under reference conditions. The absorbed dose to water is measured with ionization chambers following the German code of practice for dosimetry, DIN 6800-2, which is based on a $N_{\mathrm{Dw,Co}}$ calibration. Repeatability of the dose delivered of less than 0.2 % (k=1) is to be achieved. Reference fields have been established for electron beams with mean energies above 10 MeV. High energy photon reference fields will be established in 2003.

A database recording the performance of radiotherapy dosimetry equipment used in Germany has been established and will be further maintained at PTB. This service is in support of the German quality audit system for radiotherapy beam dosimetry which has come into operation on a commercial basis in November 2001 [1].

The construction of a new electron accelerator facility with an overall budget of about 14 M€ was approved by the federal government of Germany. The construction is expected to start in 2004. When finished in 2007/2008 the new facility will provide electron beams with energies ranging from 0.5 MeV to 50 MeV, generated by two electron accelerators. Photon and electron radiation fields as used in external radiation therapy will be generated, too. In these fields the unit of absorbed dose to water will be realized using a water calorimeter. The planning of the technical equipment and the new building is under way.

Dosimetry for Brachytherapy

Beside the field of the conventional brachytherapy with high dose rate ^{192}Ir - photon sources, the intravascular brachytherapy with beta-sources is rapidly increasing. Intravascular brachytherapy is used to avoid restenosis in coronary vessels after angioplasty. It is expected that about 60.000 patients per year in Germany will be treated with intravascular brachytherapy.

To provide traceability of the dosimetry in the clinics, PTB has developed a secondary standard based on a ^{90}Sr/^{90}Y source with an area of about 15 mm in diameter. The instrument, which will be built by a German manufacturer under a license agreement, will be calibrated in terms of absorbed dose to water by means of an extrapolation chamber which is PTB's primary standard for beta-area sources. In the course of the calibration the beta radiation field is characterized in three dimensions in a water-equivalent material of a cylindrical volume of at least 20 mm in diameter and 6 mm in depth. This enables the medical physicist in the clinic to calibrate his system for the dosimetry of sources or source trains to be used on the patient.

With a standard of the same construction PTB has established a ^{90}Sr/^{90}Y beta reference field in which calibrations of transfer dosemeters for near field dosimetry (e.g. scintillators, GafChromic film, etc) in terms of water absorbed dose are offered.

A second standard, a multi-electrode extrapolation chamber, which is to become PTB's primary standard for clinical beta-sources and source trains is being developed and partly in operation. The multi-electrode extrapolation chamber, based on the prototype described by Bambynek [2], provides the possibility of simultaneous measurements with up to 28 measurement electrodes each with only 1 mm² area. The gap between measurement electrodes and surrounding guard electrodes is 2 µm wide. It is planned, that the multi-electrode extrapolation chamber will go into operation as the primary standard by the end of this year.

For x-radiation in the energy range of 50 kV to 300 kV tube voltage PTB offers calibrations of ionization chambers in terms of absorbed dose to water. The primary standard for these radiation qualities, based on a graphite extrapolation chamber has been improved within the last year by refining the theoretical model underlying the experimental procedure [3].

For the increasing demand in calibration of clinical sources used for the treatment of prostate cancer, as ^{103}Pd- and ^{125}I-seeds, PTB is developing a Large Volume Extrapolation Chamber (LVEC), suitable for measuring the reference air kerma rate for low photon energies (< 30 keV) and low dose rates.

Air kerma standards

The PTB maintains four different free-air chambers, three parallel-plate chambers (PK10, PK100 and PK400) and one cylindrical chamber („Fasskammer“) which together cover a range of x-ray qualities produced with tube voltages between 6 kV and 400 kV. A set of three different cavity ionization chambers (two of cylindrical type and one of pancake-type) is used as primary air kerma standard for ^{137}Cs and ^{60}Co gamma rays. Key comparisons for low- and medium-energy x-rays were carried out in 1999 [4,5] and for ^{137}Cs and ^{60}Co gamma rays in 2000 [6]. Results of a bilateral comparison of the air kerma standards of the PTB and the OMH (carried out in 1999 and 2000) are available as PTB reports [7,8]. PTB took part in the EUROMET project no. 526 „Calibration of dosimeters used in mammography with different x-ray qualities” (see the special working document on this topic).

In January 2002 two new x-ray facilities were taken into operation replacing old facilities which seized to function in September 2001. The x-ray spectra of the radiation qualities realized at PTB (about 90 different qualities) were re-measured with a Ge-spectrometer. Starting off with correction factors calculated for monoenergetic radiation the correction factors for x-ray qualities were obtained by averaging this data over the photon spectra. The measuring programs were modified so as to allow the straight forward introduction of new radiation qualities, whenever necessary.

For fields of ^{60}Co and ^{137}Cs the PTB has made a change in the realization of the unit gray. The change is caused by the re-evaluation of the correction factors for wall effects and axial beam non-uniformity for cavity ionization chambers, k_{wall} and k_{an}. Starting from 1 January 2002, the reference values of the air kerma rates were increased by 0.95 % and 0.85 % in the fields of ^{60}Co and ^{137}Cs, respectively [9].

The three graphite cavity ionization chambers, normally in use as a set to operate as PTB’s primary air kerma standard in the fields of ^{60}Co and ^{137}Cs, were calibrated in terms of air kerma at different x-ray beam qualities with tube potentials between 30 kV and 300 kV using the “Fasskammer”. Using the measured x-ray spectra the air kerma response of the chambers was calculated with the EGSnrc code system and compared with the measurements. The investigation addresses the question, how accurately the absolute response of a chamber can be calculated with state-of-the-art Monte Carlo methods. The work has been published in [10].

Calibration of monochromatized synchrotron radiation with a free-air chamber

The parallel-plate free-air chamber PK100 was used for the calibration of monochromatized synchrotron radiation in the energy range from 9 keV to 60 keV at the x-ray radiometry beamline of the Physikalisch-Technische Bundesanstalt (PTB) at the electron storage ring at BESSY II. The cross sectional area of the photon beam was of the order of 1 mm^2 and hence substantially smaller than the aperture of the PK100. The power $\dot{R}$ of the photon beam was obtained from the measured ionization current I of the PK100 by:

$$\dot{R} = \frac{1}{\mu_{tr}} \frac{W_{air}}{e} \frac{I}{l} \prod_i k_i$$

where μ_{tr} is the energy transfer coefficient of air, W_{air} is the mean energy expended by an electron to produce an ion pair in dry air, *e* the elementary charge, l is the length of the measuring electrode and $\prod_i k_i$ is a product of correction factors specific for the PK100. A report of the calibration procedure is in progress.

References

[1] DERIKUM K., KAPSCH R.-P. and PYCHLAU C., First evaluation of the German quality audit system for radiotherapy beam dosimetry, Proc. 7th Biennial ESTRO Meeting, Geneva 2003

[2] BAMBYNEK M., Development of a multi-electrode extrapolation chamber as a prototype of a primary standard for the realization of the unit of absorbed dose to water for brachytherapy sources, Nucl. Instr. Meth., **A 492** (2002) 264-275

[3] KRAMER H.-M. AND GROSSWENDT B., The role of de-excitation electrons in measurements with graphite extrapolation chambers, Phys. Med. Biol., **47** (2002) 801-822

[4] BURNS D.T., BÜERMANN L., KRAMER H.-M. and LANGE B., Comparison of the air-kerma standards of the PTB and the BIPM in the low-energy X-ray range, *Rapport* BIPM-01/08 (2001).

[5] BURNS D.T., BÜERMANN L., KRAMER H.-M. and LANGE B., Comparison of the air-kerma standards of the PTB and the BIPM in the medium-energy X-ray range, *Rapport* BIPM-02/07 (2002).

[6] ALLISY-ROBERTS, BURNS D.T., BÜERMANN L. and KRAMER H.-M., Comparison of the standards of air-kerma of the PTB and the BIPM for ^{60}Co and ^{137}Cs γ rays, Draft of BIPM Rapport

[7] CSETE I., BÜERMANN L., KRAMER H.-M. and LANGE B., Comparison of the PTB and OMH Air Kerma Standards for Medium Energy X-rays, PTB Report DOS-35 (2000).

[8] CSETE I., BÜERMANN L. and KRAMER H.-M., Comparison of the PTB and OMH air kerma standards for ^{60}Co and ^{137}Cs Gamma Radiation, PTB Report PTB-Dos-40 (2002).

[9] KRAMER H.-M., BÜERMANN L. and AMBROSI P., Change in the realization of the gray at the PTB, Metrologia, **39**, (2002) 111-112.

[10] BÜERMANN, L.: Comparison of calculated and measured air kerma response of graphite cavity chambers for 30 kV - 300 kV X-ray beams. In: Recent Developments in Accurate Radiation Dosimetry. Jan P. Seuntjens and Paul N. Mobit, editors. Medical Physics Publishing (2002), S. 53 - 68